WITH INDORSEMENT

HURRICANE PROTECTION PROJECT

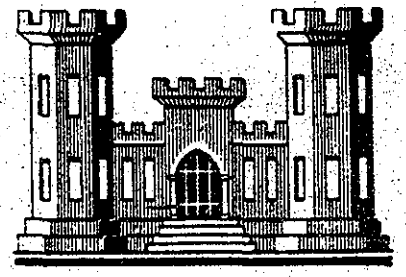
FOX POINT

HURRICANE BARRIER

PROVIDENCE RIVER, PROVIDENCE, RHODE ISLAND

DESIGN MEMORANDUM NO. 2

HYDROLOGY DESIGN



U.S. Army Engineer Division, New England
Corps of Engineers Waltham, Mass.

NOVEMBER 1959

NEDWR (17 Nov 59) 1st Ind
SUBJECT: Fox Point Hurricane Barrier, Providence, Rhode Island, Design Memorandum No. 2, Hydrology

Office, Chief of Engineers, Washington 25, D. C., 21 December 1959

TO: Division Engineer, U. S. Army Engineer Division, New England
BOSTON, MASSACHUSETTS

Approved.

FOR THE CHIEF OF ENGINEERS:

F. B. Slichter

Incls w/d

F. B. SLICHTER
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ADDRESS REPLY TO:
DIVISION ENGINEER

REFER TO FILE NO. NEDGW

17 November 1959

SUBJECT: Fox Point Hurricane Barrier, Providence, Rhode Island, Design Memorandum No. 2, Hydrology

TO: Chief of Engineers
Department of the Army
Washington, D. C.
ATTENTION: ENGWE

1. In accordance with EM 1110-2-1150 there is submitted herewith for review and approval 10 copies of the Design Memorandum No. 2, Hydrology, for the Fox Point Hurricane Barrier, Providence River, Rhode Island.

2. Preliminary plans (3 copies) of the general plan of the proposed barrier are also inclosed to assist in your review.

FOR THE DIVISION ENGINEER:

JOHN WM. LESLIE
Chief, Engineering Division

2 Incls
1. Des Memo No. 2, (10 cys)
Geology - Fox Point
2. General Plan - Fox Point
(3 cys)

FOX POINT HURRICANE BARRIER
PROVIDENCE
RHODE ISLAND

DESIGN MEMO NO. 2

HYDROLOGY

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5	General Design Memo		
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FOX POINT HURRICANE BARRIER
PROVIDENCE RIVER
RHODE ISLAND

DESIGN MEMORANDUM NO. 2

HYDROLOGY

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FOX POINT HURRICANE BARRIER
PROVIDENCE RIVER
RHODE ISLAND

DESIGN MEMORANDUM NO. 2

HYDROLOGY

NOVEMBER 1959

A. GENERAL

1. Purpose. - The purpose of this memorandum is to describe the hydrologic criteria for fresh water flooding as applicable to the design of the Fox Point Hurricane Barrier on the Providence River, Rhode Island. It includes sections on climatology, stream flow, gate and pumping design criteria.

B. BASIN DESCRIPTION

2. Location. - Fox Point Barrier will be located on the Providence River, a tidal estuary in the northern portion of Narragansett Bay. The main barrier and appurtenant structures will be located within the city limit of Providence, Rhode Island. The general location of the project is indicated on Plate No. 2-1.

3. Watershed. - The watershed above the Fox Point Barrier is roughly rectangular in shape with a length of 12 miles and a width of 6 miles with a total drainage area of 75.7 square miles. The drainage consists of two major streams, the Woonasquatucket and Moshassuck Rivers, which join to form the Providence River at a point approximately 4500 feet upstream of the project site. Both streams have relatively flat slopes with extensive swamps and ponds. The maximum elevation at the perimeter of the watershed is about elevation 600 feet m.s.l. A drainage area map and schematic river profile are shown on Plate No. 2-1.

C. CLIMATOLOGY

4. General. - The temperate and changeable climate of the Fox Point area is marked by four distinct seasons which are characteristic of the latitude and New England. The area lies in the path of the "prevailing westerlies" and the cyclonic disturbances that cross the country from the west and southwest. It is also exposed to coastal storms that move up the Atlantic seaboard, some of which are

of tropical origin. High winds, heavy rainfall and abnormally high tides are experienced in the hurricane months of August, September and October.

5. Temperature. - The mean annual temperature of the Providence area is approximately 50°F. February is the coldest month with an average temperature about 29°F, and July the warmest month with a mean temperature of 73°F. Freezing temperatures are common from late November through March. The lowest temperature recorded in Providence was -17°F. on February 9, 1934, and the highest temperature was 102°F. on August 26, 1948. Table 2-I is a summary of mean monthly and maximum and minimum temperatures recorded at the Weather Bureau station at Providence, Rhode Island for a 54-year period of record, including 1958.

TABLE 2-I

MONTHLY TEMPERATURES AT PROVIDENCE, RHODE ISLAND
(Degrees Fahrenheit)

Month	Mean	Maximum	Minimum
January	29.8	68	-9
February	29.5	69	-17
March	37.8	90	2
April	47.6	91	11
May	52.2	95	32
June	67.0	101	39
July	72.8	101	49
August	70.9	102	44
September	63.9	99	33
October	54.1	90	25
November	43.3	82	9
December	32.8	68	-12
Annual	50.6	102	-17

6. Precipitation. - The average annual precipitation at Providence, since the establishment of the station in 1904, is about 39 inches which is rather evenly distributed throughout the year. Measurable precipitation occurs on an average in about one day in three. The heaviest precipitation recorded at Providence for a 24-hour period was 6.17 inches on September 16, 1932. Table 2-II is a summary of the monthly precipitation data for Providence as measured over a period of 54 years through 1958.

TABLE 2-II

MONTHLY PRECIPITATION AT PROVIDENCE, RHODE ISLAND
(Depth in Inches)

Month	Mean	Maximum	Minimum
January	3.69	7.12	.58
February	3.08	5.80	1.18
March	3.63	8.31	.07
April	3.55	7.21	.72
May	3.06	9.25	.57
June	2.89	7.21	.04
July	2.20	6.92	.24
August	3.74	12.24	.78
September	3.18	9.79	.48
October	2.92	7.00	.15
November	3.54	8.50	.31
December	3.54	9.44	.58
Annual	39.02	58.57	29.50

7. Snow. - Snowfall as measured at Providence has averaged about 34 inches over the winters of record. A minimum of 11.8 inches was recorded during the winter of 1936-37 and a maximum of 75.6 inches during the winter of 1947-48. The snow cover usually reaches a maximum depth about February 15. Spring freshets resulting from the melting of the snow cover occur frequently but this factor alone rarely causes a serious flood. However, the possibility of heavy rain combined with snow melt creates a potential flood hazard nearly every year.

8. Storms. - The Providence River basin is subject to three general types of storm that may be classified as continental, thunderstorm, and hurricane. The rapidly moving continental or cyclonic storms that cross the basin from the west or southwest produce frequent periods of rainfall but are not extremely severe. Continental storms are apt to be more critical when they are of the stationary frontal type which may produce appreciable rainfall over a given area on several successive days. Thunderstorms may be of the frontal type associated with continental storms or of the local type and on a small drainage basin can produce high rainfall intensities. The most severe storms in the area have been of the hurricane type of tropical origin that move up the eastern seaboard. They are most likely to occur during the late summer and autumn months. The recent storms of September 1938, September 1944, August and September 1954 and August 1955 were of this type.

D. RUNOFF

9. Discharge Records. - The only U. S. Geological Survey gaging station in the Providence River basin is located on the Woonasquatucket River at Centerdale, Rhode Island. This gage, having a drainage area of 38.3 square miles, was established in July 1941 and has been in operation to date. The records from this station were utilized in the derivation of unit hydrographs studies for the project. The discharge records from this station for the period of July 1941-September 1958 are shown on Plate No. 2-2.

10. Stream Flow Data. - The annual runoff for the period of record through September 1958 for the Woonasquatucket River gage varied from 36.10 inches to 15.44 inches with a mean of 25.18 inches. Table 2-III is a summary of the maximum, minimum and mean monthly runoff for the period of record.

TABLE 2-III

MONTHLY RUNOFF

WOONASQUATUCKET RIVER AT CENTERDALE, RHODE ISLAND
July 1941-September 1958

Month	Maximum (Inches)	Minimum (Inches)	Mean (Inches)
January	4.39	0.69	2.43
February	4.67	0.88	2.61
March	6.78	1.63	4.14
April	7.68	1.67	3.59
May	5.00	1.32	2.72
June	3.99	0.87	1.73
July	1.58	0.63	1.53
August	2.52	0.52	1.01
September	3.38	0.34	0.97
October	6.01	0.31	1.10
November	6.06	0.29	1.49
December	6.04	0.70	1.86
Annual	36.10	15.44	25.18

E. RAINFALL AND RUNOFF FROM HURRICANES

11. General. - Heavy precipitation, often of torrential proportions, usually accompanies a hurricane and in some cases will arrive several days in advance. Pre-hurricane rainfall is produced when warm moist air, circulating around the eastern or northern side of a

hurricane, collides with the cold air along a far-distant, pre-existing front. The September 1938 storm, wherein the greatest part of the rainfall occurred during the four-day period before the hurricane crossed the coast of Connecticut, is an example of pre-hurricane precipitation. Approximately 90 percent of the total rainfall recorded during this storm at Providence, Rhode Island was pre-hurricane rainfall. Recent example of rainfall coincident with hurricanes are September 1944, September 1954 (Edna) and August 1955 (Diane). Hurricane rainfall has been responsible for the majority of record floods on the smaller river basins and tributaries in New England and have also produced serious flooding on major rivers which extended over a long period or followed a period of antecedent precipitation. A brief description of recent hurricane storms which cause river flooding in New England is given in the following paragraphs:

a. September 1938 Flood. - Many sections of New England had been saturated with as much as four inches of rainfall with very little surface runoff from the 12th to the 16th of September. Precipitation occurred again on the 17th and increased in intensity until the 21st when the hurricane arrived. Although Providence recorded only 3.1 inches of rain during this period, storm centers near Buck, Connecticut and Barre, Massachusetts experienced as much as 17 inches during the storm (see Plate No. 2-3). Had this storm been centered on the Providence River drainage, major river flooding would have occurred and added more damage and destruction to that already caused by the hurricane winds and tidal flooding.

b. August 31, 1954 (Carol). - Rainfall from this hurricane started early in the morning of August 31, 1954 in southern New England and ended during the afternoon in northern Maine. Precipitation measured during this storm ranged between 2 and 4.5 inches with the maximum recorded in southern New Hampshire. Providence, Rhode Island experienced less than three inches of rainfall but was damaged by the hurricane tidal surge which inundated the city.

c. September 11, 1954 Flood (Edna). - The rainfall associated with this hurricane amounted to about 4.4 inches at Providence and 6.3 inches at Woonsocket. There was very little antecedent precipitation, but the high concentration of rainfall in about a six-hour period produced serious flooding on many streams in Rhode Island. This flood was the maximum of record for the Woonasquatucket River at Centerdale, Rhode Island with a peak discharge of 1100 c.f.s. The computed total flow from the Moshassuck and Woonasquatucket Rivers at Providence was estimated to have a maximum discharge of about 6,000 c.f.s.

d. August 19, 1955 Flood (Diane). - Torrential rains accompanied this hurricane, falling on ground already saturated by the heavy precipitation which accompanied Hurricane Connie during the previous week (August 11-15). In less than a two-day period, over six inches of rain were recorded in Providence and 10.4 inches at Woonsocket. Despite the heavy rain, the total runoff as measured at Centerdale represented only about 0.4 inches of runoff for the entire 38.3 square miles of drainage. Runoff computations indicate that this flood may have been the largest of record in the lower Woonasquatucket River. The maximum discharge for the entire drainage area above the project site was estimated to be about 6400 c.f.s.

F. UNIT HYDROGRAPH ANALYSIS

12. General. - Stream flow records from July 1941 to date are available for the U. S. Geological Survey gaging station located on the Woonasquatucket River at Centerdale, Rhode Island. These records which represent flows from a drainage area of 38.3 square miles are shown on Plate No. 2-2. Information on earlier flows or peak flows for other streams in the drainage area above the project site are not available. Precipitation records are available from records at Providence and Woonsocket and a non-recording station at Greenville. The location of these stations are shown on Plate No. 2-1.

13. Unit Hydrograph for U. S. G. S. Gage at Centerdale. - A review of the stream gaging and precipitation records indicated the basin has not experienced a major flood. Minor floods have been so distorted by the large amount of natural and artificial storage that the rainfall-runoff relationships would be of little value, if it were assumed that the total drainage area contributed to the runoff. It was found, in many cases, a more realistic rainfall runoff relationship existed, if it was assumed that the flood hydrograph represented flow from a net area of 13.8 square miles below the Woonasquatucket Reservoir. Evidently the large amount of natural and artificial storage in the upper 24.5 square miles has a strong retarding influence on the development of floods, especially the hurricane storms having short-duration, high-intensity rainfall. The following minor floods were analyzed assuming contribution from only the net drainage area of 13.8 square miles: December 1944, May 1954, September 1954, December 1954, August 1955 and April 1958. In addition, the floods of October 1955, November 1955 and April 1957 were analyzed assuming the runoff came from the total 38.3 square miles. All other significant rises were found to contain some snowmelt and therefore were not used for unit hydrograph analyses. Summaries of these analyses along with detailed basic data sheets are shown in Plates No. 2-4 through No. 2-25.

14. Rainfall-Runoff Relationships. - As discussed in the previous paragraph, unit hydrograph studies indicate that natural and artificial storage has been very influential in the rainfall-runoff relationships in this basin. As an example, the flood of August 1955 yielded a total runoff of 0.4 inches from an average basin rainfall of 8.4 inches. Assuming that the 24.5 square miles about Woonasquatucket Reservoir did not contribute, the resultant runoff represents 1.1 inches from 13.8 square miles or only 13 percent of the rainfall. If it is further assumed that the runoff came from only the local area of 5.5 square miles below Georgiaville Pond, the resultant runoff represents 2.75 inches, or 33 percent of the average rainfall. It is evident that the losses due to natural or artificial conditions are unusually high. Table 2-IV, on Page 8, is a summary of rainfall-runoff relationships for floods analyzed from records at Centerdale, Rhode Island, assuming contributions from various drainage areas.

15. Adopted Unit Hydrographs. - The unit graph derived from the flood of September 1954 was adopted since it was the most critical for a drainage area of 13.8 square miles. A unit graph for the upper 24.5 square miles was obtained by subtracting the unit graph for the net area from a total unit hydrograph. The difference between the two unit graphs represented the unit graph for the 24.5 square miles as routed to Centerdale. These adopted 3-hour unit hydrographs are shown on Plate No. 2-27, whereon the areas are designated as W_3 and W_4.

16. Unit Graphs for Ungaged Areas. - The drainage areas of the Woonasquatucket and Moshassuck Rivers were each divided into four sub-areas to facilitate the derivation of synthetic unit hydrographs for the ungaged areas (see Basin Map, Plate No. 2-1). The sub-areas were selected to reflect the different runoff characteristics between urban and sub-urban areas. The unit hydrographs for each of these areas were developed by the use of "Snyder's" coefficients and the urban areas were checked by both the rational formula and method used in Synthetic Flood Frequency, Journal of Hydraulics Division, Proceedings ASCE, October 1958 by Franklin F. Snyder. The adopted coefficients are summarized in Table 2-V and the unit hydrographs are shown on Plates No. 2-26 and No. 2-27.

TABLE 2-IV

RAINFALL-RUNOFF RELATIONSHIPS
WOONASQUATUCKET RIVER AT CENTERDALE, RHODE ISLAND

	Total Precipitation	Runoff (Rainfall Excess) Inches	% of Total	Total Losses in Inches	Max. Hourly Rainfall	Loss in % Max. Hourly R.F.	Peak Discharge (c.f.s.)
Contributing area assumed - 5.5 sq. miles							
August 1955	8.4	2.75	33	5.65	2.60	8	520
Contributing area assumed - 13.8 sq. miles							
Nov-Dec 1944	2.3	0.9	39	1.4	.41	34	465
May 1954	2.1	1.5	71	.6	.20	10	350
September 1954	5.3	1.7	32	3.6	.96	42	1100
December 1954	1.5	1.3	59	0.2	.35	6	520
August 1955	8.4	1.1	13	7.3	2.60	58	520
April 6, 1958	1.74	1.05	60	0.7	.25	28	420
Contributing area assumed - 38.3 sq. miles							
October 1955	6.7	3.0	45	3.7	.32	31	955
November 1955	2.9	1.0	35	1.9	.27	18	600
April 1957	2.1	1.4	67	0.7	.20	25	450

TABLE 2-V

UNIT HYDROGRAPH ANALYSIS

Area Designation	Drainage Area Sq. Miles	L Miles	L_{ca}	t_p	q_p c.f.s. s.m.	C_t	$C_p 640$
Woonasquatucket River							
W_1	5.3	3.45	1.85	3.0	189	1.72	567
W_2	8.7	4.70	2.20	7.5	52	3.72	390
W_3	13.8	6.40	3.20	10.0	46	4.04	460
W_3W_4	38.3	13.5	5.5				
Moshassuck River							
M_1	4.63	4.7	2.8	4.0	142	1.84	570
M_2	7.33	4.9	2.7	8.0	50	3.70	400
M_3	2.76	1.8	1.0	2.0	199	1.68	400
M_4	2.65	5.1	2.2	7.6	52	3.70	400

G. DESIGN STORMS

17. General. - The probability of a major river flood coincident with a hurricane tide is remote. The hurricane of September 1938 and August 31, 1954 (Carol) caused the greatest tidal damage in Providence in recent years but in both storms the total precipitation in the area was about three inches. The reverse is true in the cases of the hurricane of September 1954 (Edna) and August 19, 1955 (Diane). During these storms which caused the greatest river flooding, tides were only slightly above normal and caused no serious damages in Providence.

18. Since the September 1938 storm produced the highest amount of rainfall associated with a hurricane and tidal flooding in southern New England, it was adopted as a design storm. The maximum precipitation for this storm was concentrated over Portland (Buck) Connecticut, about one mile south of Middletown where a total of 17 inches was recorded for the period September 17-21. This storm center was transposed over the Woonasquatucket and Moshassuck Rivers by two different methods. First, the total rainfall from depth - area relationships was selected and the rainfall pattern rearranged to give the most critical runoff: secondly, the storm was transposed with the rainfall pattern exactly as experienced at the storm center. The mass curves of rainfall for both transpositions are shown on Plate No. 2-28.

19. Rainfall Frequency. - The relative frequency of storm runoff for Providence, Rhode Island, was determined from U. S. Weather Bureau, Technical Paper No. 25, Rainfall Intensity-Duration-Frequency Curves, published in December 1955. Table 2-VI is a summary of the 12-hour rainfall and runoff from all season rainfall frequencies for the Providence urban area, assuming average losses about .15 inches per hour.

TABLE 2-VI

RAINFALL - RUNOFF FREQUENCY DATA

Frequency in Years	12-Hour Rainfall	Runoff in Inches	Peak Discharge in c.f.s. *
5	2.84	1.90	3,400
10	3.84	2.40	4,500
25	4.56	3.00	5,600
50	5.28	3.60	6,600
75	5.64	4.10	7,900
100	6.00	4.30	8,300

*Includes estimate of contribution to the peaks from upstream areas.

H. DESIGN FLOODS

20. General. - Although Providence, Rhode Island has not experienced a major river flood coincident with a damaging hurricane tide within the period of record, the physical possibility exists with every future hurricane. Therefore, studies were made of various storms experienced in New England that could be considered as being associated with hurricanes. The following is a brief description of the major storms and assumed coincident tide conditions considered:

a. Trial I. - This flood was derived by applying the transposed September 1938 rainfall, rearranged in the most critical pattern, to the unit graph adopted for each sub-area assuming a uniform loss of 0.1 inches per hour. The hydrographs from each area were combined with estimated routing coefficients resulting in a total flood at the junction of the Moshassuck and Woonasquatucket Rivers with a peak discharge of 10,000 c.f.s.

b. Trial II. - The rainfall used in this trial was the transposed September 1938 storm exactly as experienced at Buck, Connecticut with an assumed uniform loss of 0.1 inches per hour. This yielded a total discharge of 9,800 c.f.s.

c. Trial III. - As analysis of the rainfall-runoff relationship had indicated that the characteristics of the drainage areas produced varying losses from storage and infiltration, a trial was made using the same rainfall as Trial II, but modified by weighted losses. The losses varied from 100 percent in the earlier part of the storm to 0.1 inches per hour in the final period. These rainfall excesses, when applied to the adopted unit hydrograph and combined, resulted in a peak discharge of 8,900 c.f.s. The total hydrograph for Trials I, II, and III are shown on Plate No. 2-29.

d. Trial IV. - Considerations were given to considering smaller floods coincident with tidal surges. For this purpose the flood of September 1954, the maximum of record in the Woonasquatucket River at Centerdale, Rhode Island, was developed for the entire area. This was done by using the experienced rainfall with weighted losses combined with the adjusted unit hydrographs for the ungaged areas. The resultant peak discharge for the entire area was 6,000 c.f.s.

e. Trial V. - Although the runoff at Centerdale during the August 1955 flood was minor, the flow in the urban areas in the lower part of the basin was probably substantial. Therefore, a trial was made using the experienced precipitation of 8.3 inches with weighted losses. The resultant total peak discharge was about 6,400 c.f.s. A plot of the September 1954 and August 1955 floods are shown on Plate No. 2-30.

21. Standard Project Flood. - The standard project flood for the total area was determined in accordance with Civil Engineer Bulletin 52-8 with adopted unit hydrographs for the basin sub-divisions. A rainfall excess of 9.12 inches was developed from 48 hours rainfall of 12.0 inches with maximum losses of 0.1 inches per hour. The peak of the SPF for the total drainage area would be about 24,000 c.f.s. It was considered that the flood would not be practical for coincident runoff with a hurricane but would be used to test the capacity of the gated openings through the barrier to insure that the restriction would not contribute to damage during a major river flood with normal high tide conditions.

I. DESIGN TIDES

22. General. - The normal range of tides at Providence, Rhode Island is between 2.1 m.s.l. and 2.4 m.s.l. with maximum spring tide occasionally reaching [illegible] feet, m.s.l. Recent abnormal tides experienced at Providence were at elevation 15.7 in September 1938 and 14.7 in August 1954 (Carol). The design tide for the proposed barrier has been computed to be at a still water elevation of 20.5 and would exceed the damage stage at elevation 6.0 for a period of about six hours. The derivation of this design tide is discussed in Design Memorandum No. 4, "Tidal Hydraulics".

J. PUMPING REQUIREMENTS

23. General. - The three basic conditions to be considered in the selection of pumps are (1) peak rate of inflow (2) maximum tide conditions and (3) probability of coincidence of the previous two conditions. The studies indicated that the most critical pumping requirement for any combination of tide or peak inflow resulted when the peak tide occurred one to two hours prior to the peak inflow. Various combinations of these conditions were tested, assuming the following basic rules of operation:

a. The barrier gates will be closed during the low flow period preceding a forecast hurricane tide at Providence. The stage for closing will depend on the concurrent total rate of flow on the Woonasquatucket and Moshassuck Rivers, but will not exceed mean sea level 0.0.

b. For low or moderate rates of local inflow from the rivers the pool behind the barriers will be maintained at elevation 0.0 by operation of the pumps as required. For higher rates of inflow the pool will be pumped down to an elevation not lower than -3.0.

c. Pumps will be operated to maintain the above described pool elevations insofar as possible during the period that gates are closed. Pool stages should not exceed elevation +3.0 during storm conditions in order to provide sufficient gradients for the municipal drainage systems.

d. Whenever the pool elevation upstream of the barrier exceeds the tide elevation by an appreciable amount, the barrier gates may be opened to "dump" the pool.

24. Overtopping. - In addition to the above basic conditions, the pumping capacity must be sufficient to take care of overtopping from wind and wave action during a design hurricane condition. Overtopping during the design tide extends over a period of five hours and has a computed volume of 126 acre-feet and a peak rate of discharge of 1160 c.f.s. The maximum overtopping rate for a recurrence of the September 1938 tide was computed to be 50 c.f.s. This was considered to be negligible as a factor for pumping requirements.

25. Selected Pumping Capacity. - The five trial floods discussed in Paragraph 20 were combined with the design tides and the September 1938 tide to determine the most critical sequence of events with different pump capacities. The rating curve shown on Plate No. 2-32 was one of several supplied by manufacturers which were used for these studies. A summary of the more critical combinations of floods, tide and pumping capacities is shown on Table 2-VII on page 13.

TABLE 2-VII

FOX POINT HURRICANE BARRIER

SUMMARY OF TRIALS TO DETERMINE PUMPING REQUIREMENTS

STORM	TIDE		MAXIMUM INFLOW		Pump Capacity 20-Ft Head(b)	Maximum Pool Elevation
	Condition	Maximum Elevation	River Inflow	With Overtopping		
		(ft.m.s.l.)	(c.f.s.)	(c.f.s.)	(c.f.s.)	(ft.m.s.l.)
Trial III-Design (a)	Design	20.5	8,920	9,980	5,600	15.20
					7,000	9.70
					8,400	2.74
" " " "	1938	15.7	8,920	8,970	5,600	11.27
					7,000	5.85
					8,400	-1.32
75-Year	Design	20.5	7,900	9,060	5,600	9.46
					7,000	5.06
					8,400	1.16
"	1938	15.7	7,900	7,950	5,600	5.55
					7,000	0.26
					8,400	-.58
100-Year	Design	20.5	8,300	9,460	5,600	10.60
					7,000	6.71
					8,400	0.74
"	1938	15.7	8,300	8,350	5,600	7.90
					7,000	1.35
					8,400	-1.00

(a) Transposed September 1938 storm with weighted losses.
(b) Equivalent to 4, 5 and 6 pumps of proposed type.

26. It was concluded that a design pumping capacity of approximately 7,000 c.f.s. at a static head of about 20 feet would provide a high degree of protection against interior flooding and should be used as a basis for design studies. The selected pumping capacity would be adequate to provide protection for the following combinations of tidal and river flooding:

a. All floods of record in the basin coincident with the proposed design tide at elevation 20.5 feet, m.s.l.

b. The transposed September 1938 storm (17 inches of rainfall in 4 days) coincident with the September 1938 tide at elevation 15.7 feet, m.s.l.

c. A flood comparable to the runoff from a 75-year all-season rainfall, occurring in critical sequence with the proposed design tide of elevation 20.5 feet, m.s.l.

d. A flood comparable to the runoff from a greater than 100-year all-season rainfall, occurring in critical sequence with the maximum tide of record (15.7 feet, m.s.l. in September 1938).

27. The transposed 1938 storm coincident with the design tide would result in a maximum pool elevation of 9.7 feet, m.s.l., which is 3.7 feet above the beginning of damage stage. This stage would cause serious damage to downtown Providence but it is considered that the improbability of these coincident events precludes their use in design.

K. HYDRAULIC FEATURES

28. General. - The detailed analysis of the hydraulic features of the Fox Point Hurricane Barrier will be discussed in the respective memoranda describing those features. The following is a summary of the general hydraulic problems and conclusions relating to the pump capacities and operational requirements of the project.

a. River Gates. - The location of the hurricane barrier is considered to be upstream of normal navigation, therefore, the most critical conditions governing the size of the gated openings are (1) capacity to maintain the existing tidal fluctuations in the pool behind the barrier and (2) capacity to permit a major river flood to flow through the barrier openings without introducing major head losses. The proposed three tainter gates 40 feet long and 40 feet high, with a sill at elevation -15.0 m.s.l. will adequately satisfy these conditions. Studies indicate that normal tide ranges will not be affected except for a very slight lag in time. The standard project flood discharge of 24,000 c.f.s. would flow through these

gates with a head of approximately 2.3 feet which will not cause damages at normal high tides. The gates are also considered to have an opening high enough to permit small boats or work barges that may wish to get upstream for maintenance purposes. Backwater computations indicate that the tidal portion of the Woonasquatucket and Moshassuck Rivers have a channel capacity at normal high tide of 6,000 c.f.s. and 3,600 c.f.s., respectively. For greater discharges there will be overbank flow, but such flows will return to the Providence River above the hurricane barrier.

b. Number and Type of Pumps. - The rating curves shown on Plate No. 2-32 indicate that a single pump can discharge 1,400 c.f.s. with a static head of 20 feet. Therefore, five of these pumps would be required to pump the design discharge of 7,000 c.f.s. The pumps under consideration are of the flared tube type with a diameter of 120 inches. The discharge at low heads are constant until a syphon develops with a tailwater surface elevation of about 6.3 feet, m.s.l.

c. Cooling Water Canal. - It was considered possible that the changes in current patterns and vertical mixing by the barrier might result in increases in water temperatures upstream from the structure where the Narragansett Electric Company operates two power generating stations which draw condenser cooling water from the Providence River. Tests were made on the existing Narragansett Bay model located at the Waterways Experiment Station at Vicksburg, Mississippi (Interim Report 3, Sept. 1959) and the result indicated that the reduced vertical circulation would cause an increase in the average water temperature in the upstream area by 3.0 to 3.5 degrees and would make a slight reduction in the downstream temperatures. Therefore, it was decided that a cooling water canal that would draw water from downstream through the barrier would be required. Present plans are for a canal about 1500 feet in length to provide the necessary cooling water at a maximum rate of 1,000 c.f.s. The hot exhaust water will be carried across and discharged beyond the canal into the Providence River upstream of the barrier. The downstream end of the canal will have a gated opening with an invert elevation at -18.0 so that during the short duration of hurricane tides the barrier will be closed off and the power company will obtain their cooling water from the river upstream.

L. OPERATION OF PUMPS AND GATES

29. Operational Requirements. - As stated in paragraph 23, the barrier gates will be closed during the low tide preceding a forecast hurricane tide. Closing during the low tide permits the pool to be drawn down by pumps to -3.0 in a minimum time and with a minimum energy required, thereby providing as much storage as possible in the event that a major flood should develop. The limit of -3.0

was set so as not to introduce new loading conditions on existing retaining walls and foundations of buildings adjacent to the river. The upper limit that will be permitted in the pool behind the barrier is elevation +3.0. This would permit the existing storm drains to function normally, although significant damage in Providence does not start until the river rises above elevation +6.0 feet m.s.l.

30. Pumping Schedule. - Recording gages will be installed, both upstream and downstream of the barrier with recorders located in the pumping station. With substantial river inflow the pumps will be operated manually according to the following schedule:

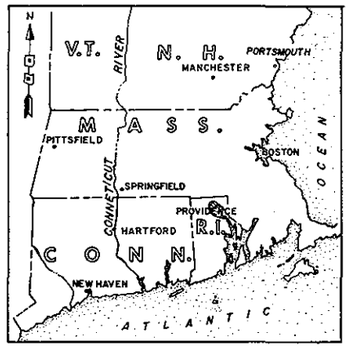
Upstream Pond Elevation	Number of Pumps
-2.5	1
-2.0	2
-1.5	3
-1.0	4
-0.5	5

This schedule will be maintained unless the water surface downstream becomes significantly lower than the upstream pool, at which time the barrier gates should be opened and pumping discontinued.

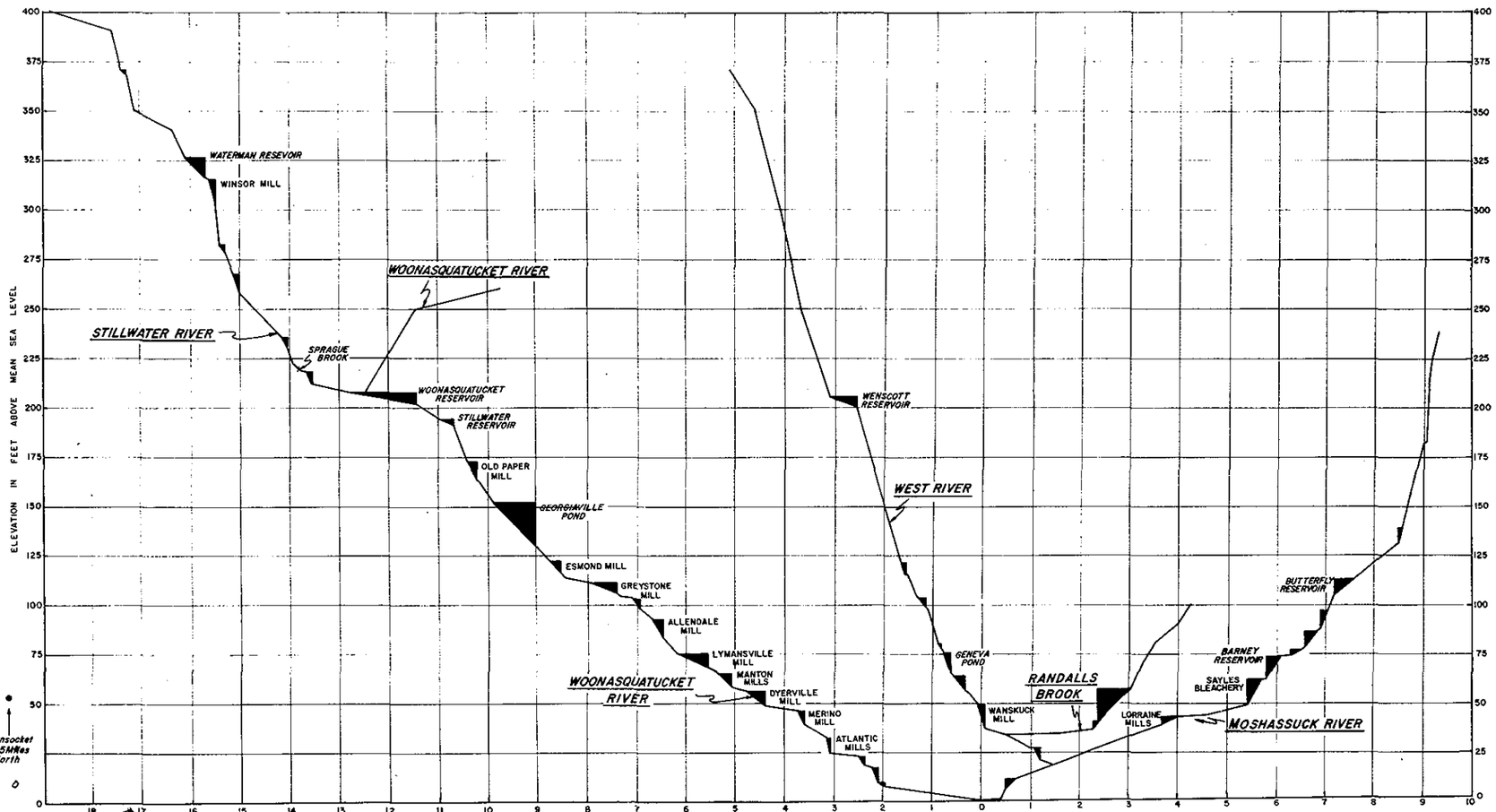
31. Cooling Water Intake Gates. - The gates to the cooling water canal need not be closed at the same time as the main barrier gates are closed. The canal gates will be throttled to maintain a discharge necessary to the operation of the power company and the warm discharge water pumped through the barrier along with river inflow. This condition will be maintained until three pumps are required to satisfy the pumping schedule. At this time the fresh water inflow will be in excess of 3,000 c.f.s. which would provide an adequate flow for mixing with the warm exhaust water and should not create a harmful situation for the power company in using the main river water.

32. Time of Initial Closure. - The U. S. Weather Bureau is continually improving its methods for forecasting the tracks of hurricanes, but as yet cannot pinpoint in advance of 6 hours the location of a hurricane striking the coast. Experience in New England has indicated that a hurricane can travel from Cape Hatteras to the Narragansett Bay Area in six hours or less (September 1938). Therefore, until forecasting methods improve, it will be necessary to close the barrier gates at about low tide when a hurricane is located at about the latitude of Cape Hatteras and is moving northward. This may cause many false alarms but is considered necessary to prevent major damages to the City of Providence, Rhode Island. Examples of proposed operation for tide conditions similar to those experienced in 1938 and the design tide, combined with selected river flood are

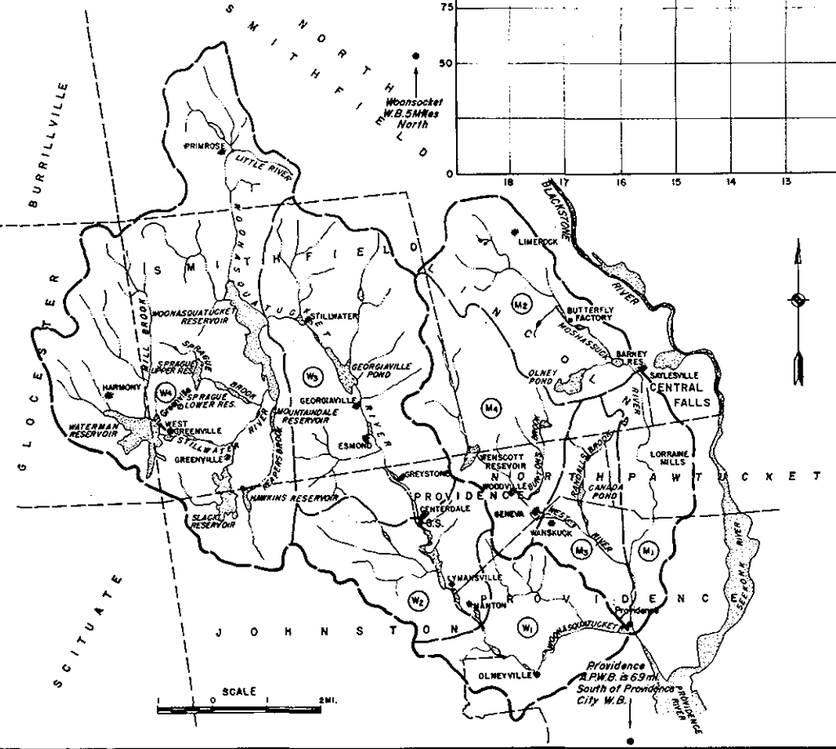
shown on Plate Nos. 2-33 through 2-35. Details of the proposed operation will be discussed further in other design memoranda as the detail design problems become resolved.



LOCATION MAP
SCALE IN MILES
16 0 16 32 48



MILES FROM JUNCTION OF WOONASQUATUCKET & MOSHASSUCK RIVERS



COMPONENT AREA	DRAINAGE AREA	COMPONENT AREA	DRAINAGE AREA
M_1	4.63	W_1	5.3
M_2	7.33	W_2	8.7
M_3	2.76	W_3	13.8
M_4	8.65	W_4	24.5
TOTAL MOSHASSUSK	23.37	TOTAL WOONASQUATUCKET	52.3

HURRICANE PROTECTION PROJECT
FOX POINT
HURRICANE BARRIER
BASIN MAP AND PROFILE
PROVIDENCE RHODE ISLAND

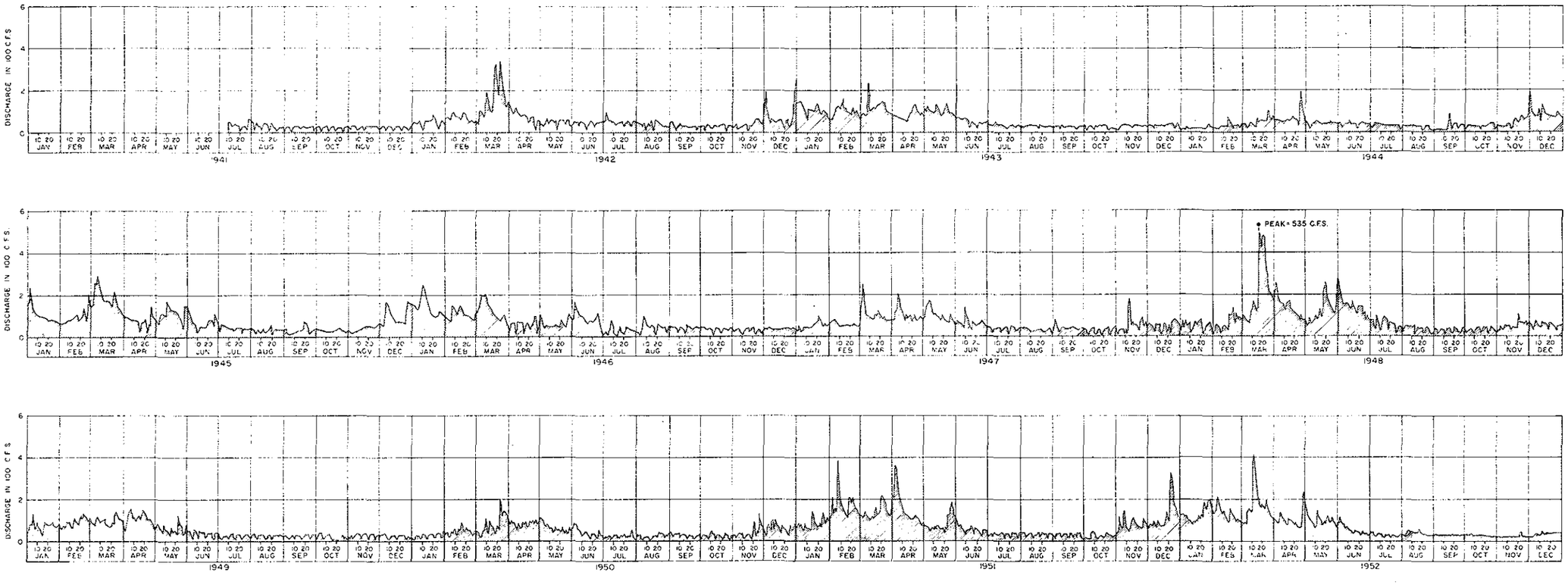
U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS WALTHAM, MASS.

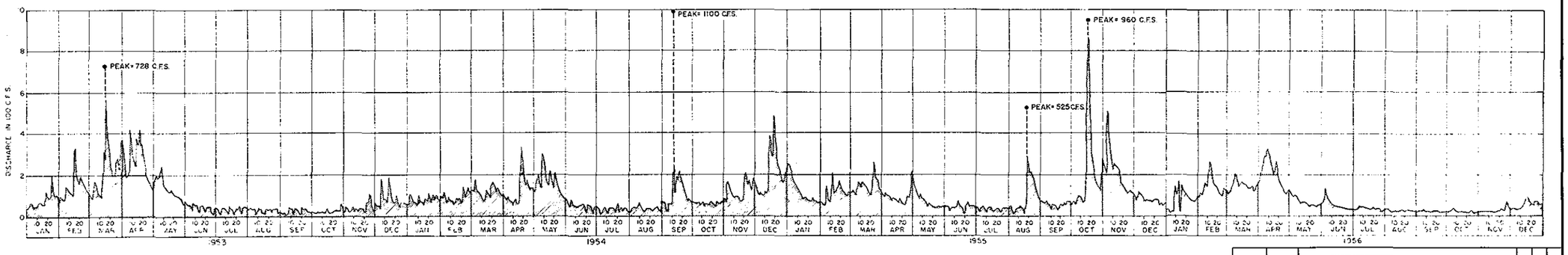
NOVEMBER 1959

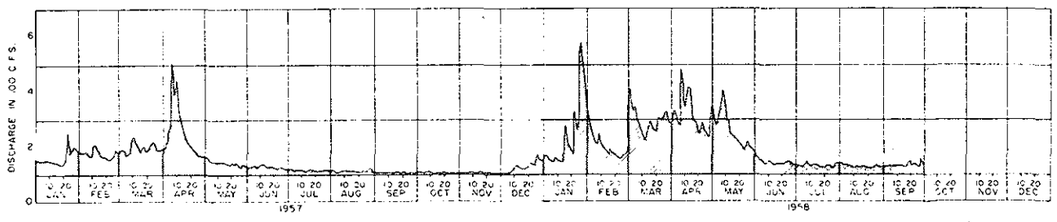
PLATE NO. 2-1

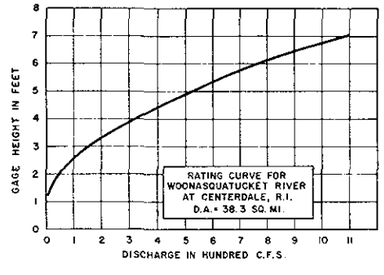
CORPS OF ENGINEERS

U. S. ARMY









REVISION	DATE	DESCRIPTION	BY

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS

DR. BY | TR. BY | CK. BY

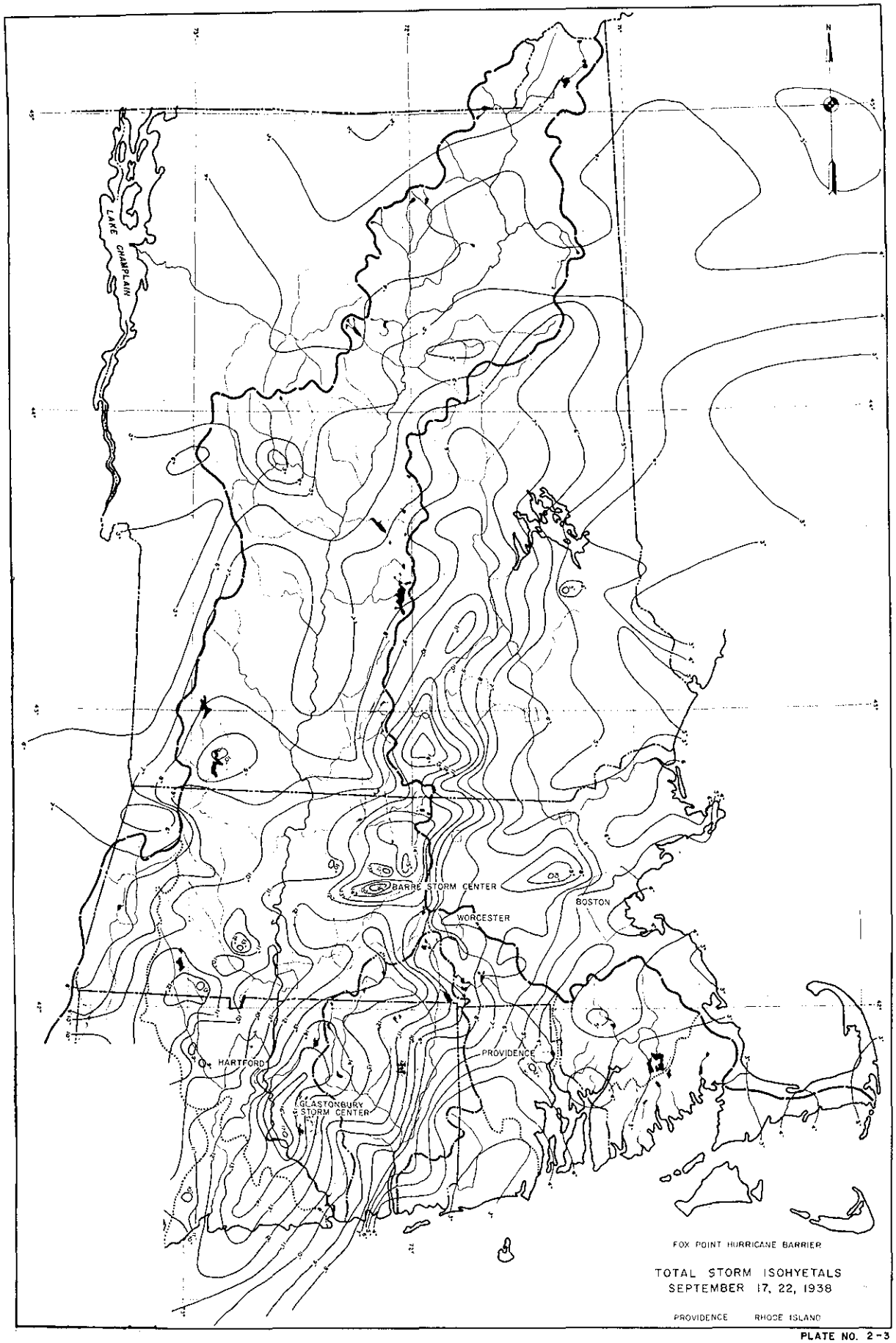
PROJECT ENGINEER
SUBMITTED BY
CHIEF PLANS & APP'S BRANCH
APPROVED
CHIEF ENGINEERING DIV

HURRICANE PROTECTION PROJECT
FOX POINT HURRICANE BARRIER
HYDROGRAPHS
AT CENTERDALE R.I.
1941 TO 1958
WOONASQUATUCKET RIVER, RHODE ISLAND

APPROVED
DATE
COL., C.E. DEPUTY DIVISION ENGINEER

SCALE
SPEC. NO. CIV ENG-19-016-
DRAWING NUMBER
SHEET

PLATE NO. 2-2



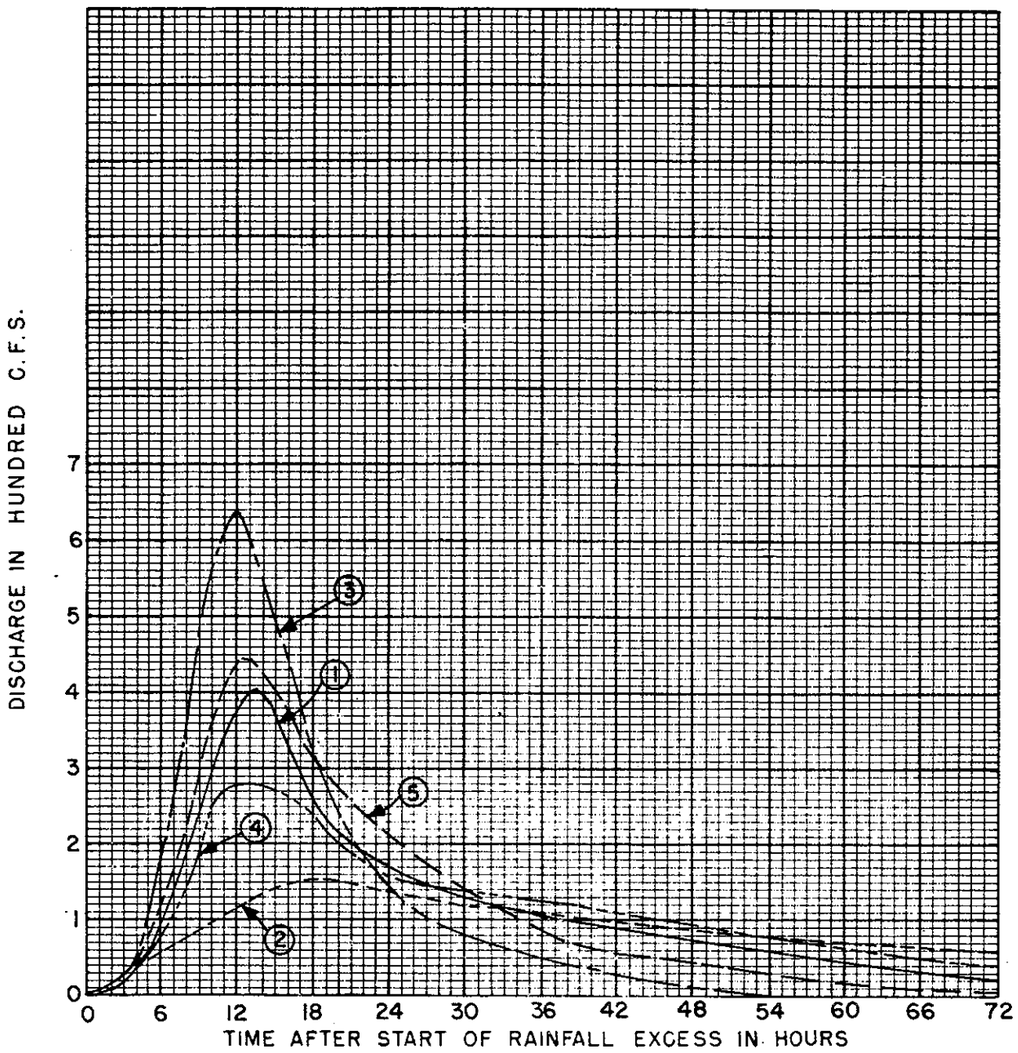
TOTAL STORM ISOHYETALS
SEPTEMBER 17, 22, 1938

PROVIDENCE RHODE ISLAND

PLATE NO. 2-3

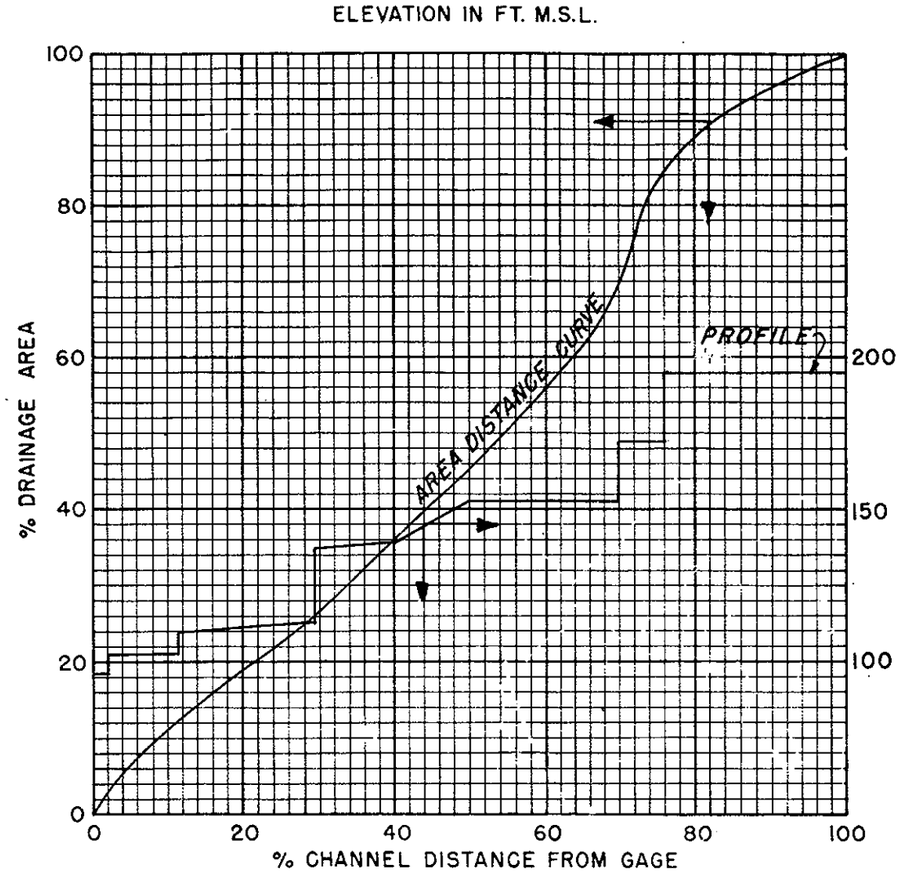
DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

OBSERVED UNIT HYDROGRAPHS



DRAINAGE AREA CHARACTERISTICS

DRAINAGE AREA	13.8	sq. mi.	L	6.40	mi.
MAXIMUM ELEVATION	470	ft. m.s.l.	L_{ca}	3.20	mi.
MINIMUM ELEVATION	95	ft. m.s.l.	$(LL_{ca})^{0.3}$	2.47	
MEAN ELEVATION (weighted)		ft. m.s.l.	DRAINAGE DENSITY		mi/sq.mi.
LAND SLOPE		ft./mi.	MAP SCALE		
MAIN STREAM SLOPE	15.6	ft./mi.	METHOD OF FLOW SEPARATION		
			BASIN SHAPE FACTOR		



DATA FROM OBSERVED UNIT HYDROGRAPHS

DATE OF RAINFALL	LEGEND	AVE. P (In.)	RAINFALL EXCESS DURATION (hr.)	RAINFALL EXCESS AMOUNT (In.)	L_{cP} (mi.)	STAGE RECORD	Q_{pR} (cfs.)	$Q_{p\ tr=\ hrs.}$ (cfs.)	t_{pR} (hr.)	t_p (hr.)	t_v (hr.)	C_{tR}	C_p640	K_m (hr.)	T_c (hr.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
NOV.-DEC. 1944	——①	2.34	6	0.93		REC	400	430	8.3	8.5	15.0	3.4	460		
MAY 1954	-----②	2.06	12	1.51		REC.	152	172	10.0	12.0	33.0	4.0	148		
SEPT. 1954	—·—③	5.34	5	1.66		REC.	637	637	6.7	10.0	8.0	3.4	460		
DEC. 1954	—·—·④	2.16	9	1.16		REC.	276	367	7.7	11.5	19.7	3.4	460		
AUG. 1955	———⑤	8.28	1	1.06		REC	445	445	11.5	9.5	14	4.7	380		

Note: *Drainage Area = 13.8 S M.*

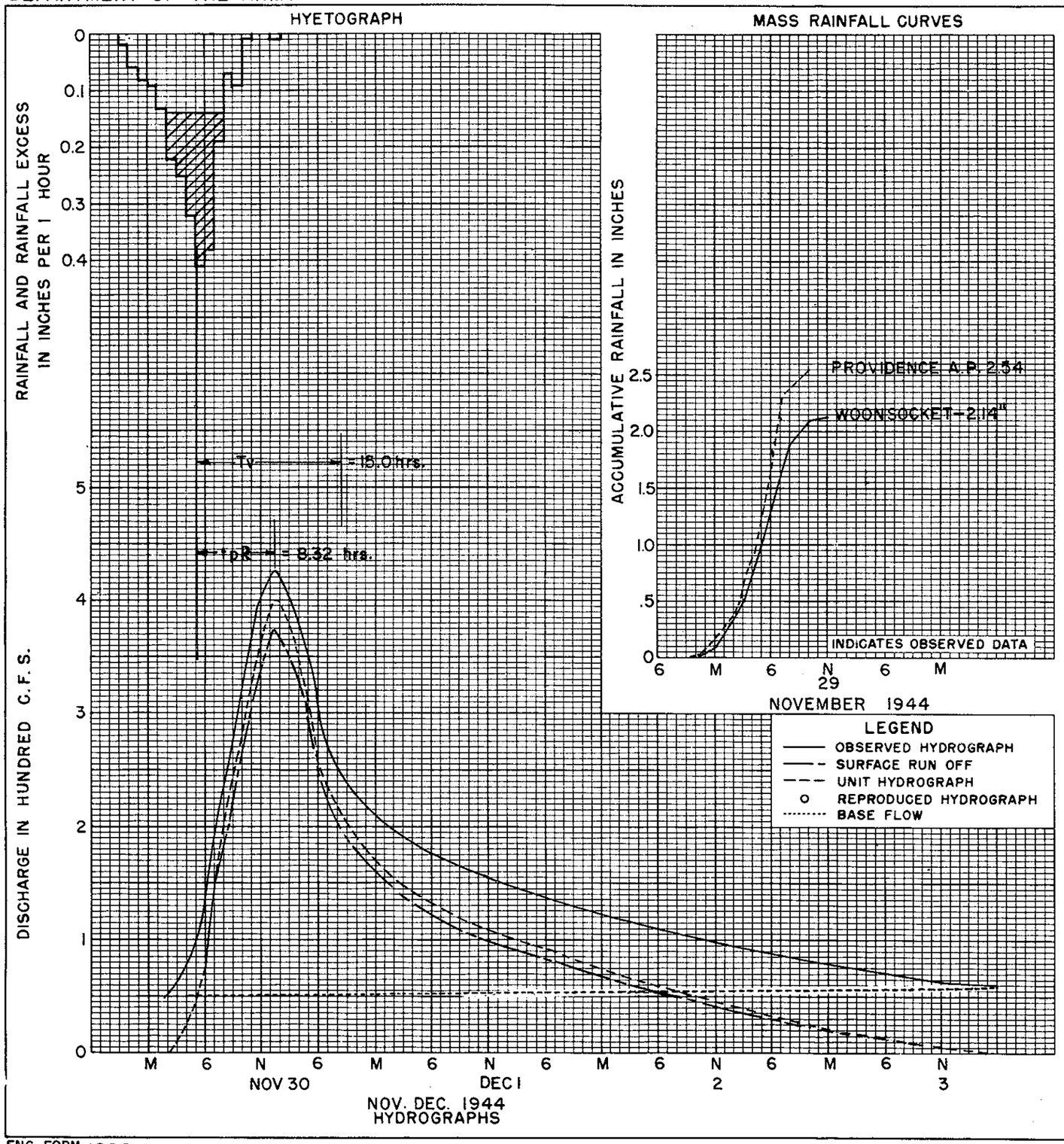
HURRICANE PROTECTION PROJECT
FOX POINT HURRICANE BARRIER
WOONASQUATUCKET RIVER
AT CENTERDALE, R.I.
UNIT HYDROGRAPHS PERTINENT DATA
NEW ENGLAND DIVISION - WALTHAM MASS
OCTOBER 1959

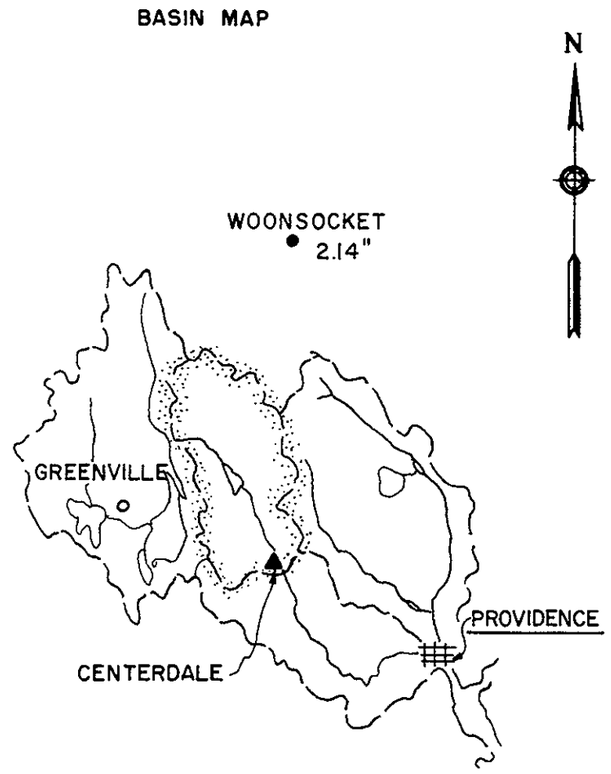
ENG FORM 1 NOV 49 1821

PLATE NO. 2-4

DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS





Note: *Drainage Area = 13.8 S.M.*

LEGEND

	REC.	NON REC.
PRECIPITATION GAGES	●	○
STREAM GAGES	▲	△
ISOHYETS	——	——
THIESSEN POLYGON	- - - - - - - -	
ZONE BOUNDARY		

BASIC DATA
(Sheet 1 of 2)

HURRICANE PROTECTION PROJECT

FOX POINT HURRICANE BARRIER

WOONASQUATUCKET RIVER
AT CENTERDALE, R.I.
STORM OF NOVEMBER-DECEMBER 1944

NEW ENGLAND DIVISION - WALTHAM MASS.
OCTOBER 1959

ENG FORM 1822
1 NOV 49

PLATE NO. 2-5

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 2 OF 2)

(7) STREAM AND STATION Woonasquatucket River at Centerdale 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM Nov-Dec 1944 (9) OFFICE New England Division

(10) DRAINAGE AREA 13.8 SQ.MI. (11) L 6.40 MI. (12) L_{ca} 3.20 MI. (13) $(LL_{ca})^{0.3}$ 2.47

(14) AVERAGE RAINFALL 2.34 IN. (15) t_R 6 HRS. (16) DIRECT RUNOFF 0.93 IN.

(17) Q_{pR} 400 CFS. (18) q_{pR} 62.5 CFS/SQ.MI. (19) Q_p 430 CFS. (20) t_{pR} 8.3 HRS.

(21) t_p 8.5 HRS. (22) t_v 15.0 HRS. (23) C_{tR} 3.37 (24) C_{p640} 460 W_{50} 13 HRS. W_{75} 6 HRS.

TIME November 1944 (25)	OBSERVED DISCHARGE (~~1000~~ CFS) (26)	ESTIMATED BASE FLOW (~~1000~~ CFS) (27)	DIRECT RUNOFF (~~1000~~ CFS) (28)	OBSERVED 4 HR UNIT HYDROGRAPH (~~1000~~ CFS) (29)	ADJUSTED 3 HR UNIT HYDROGRAPH (~~1000~~ CFS) (30)	REPRODUCED STORM HYDROGRAPH (~~1000~~ CFS) (31)	(32)	(33)
M	50	50	0	0	0			
Nov 30 3A	60	50	10	11	15			
6	127	50	77	83	85			
9	275	51	224	241	225			
N	395	51	344	370	410			
* 3P	402	51	351	*377	*362			
6	297	52	245	263	240			
9	237	52	185	199	195			
M	210	52	158	170	170			
Dec 1 3A	190	53	137	147	150			
6	175	53	122	131	135			
9	163	53	110	118	120			
N	153	54	99	106	109			
3P	145	54	91	98	97			
6	137	54	83	89	87			
9	130	55	75	81	78			
M	123	55	68	73	70			
Dec 2 3A	116	55	61	66	62			
6	110	56	54	58	56			
9	104	56	48	52	49			
N	98	56	42	45	43			
3P	92	57	35	39	37			
6	87	57	30	32	33			
9	83	57	26	27	29			
M	78	58	20	22	25			
Dec 3 3A	74	58	16	17	21			
6	70	58	12	13	18			
9	67	59	8	9	15			
N	64	59	5	5	12			
3P	62	59	3	2	9			
6	60	60	0	0	6			
9	60	60			3			
M	60	60			0			
Totals	4554	1815	2739	2944	2965			
*Peak								
1:30	425	51	374	400	430			

DATE COMPUTED BY J. F. and A. M.

ENG FORM NOV 1823

PLATE NO. 2-6

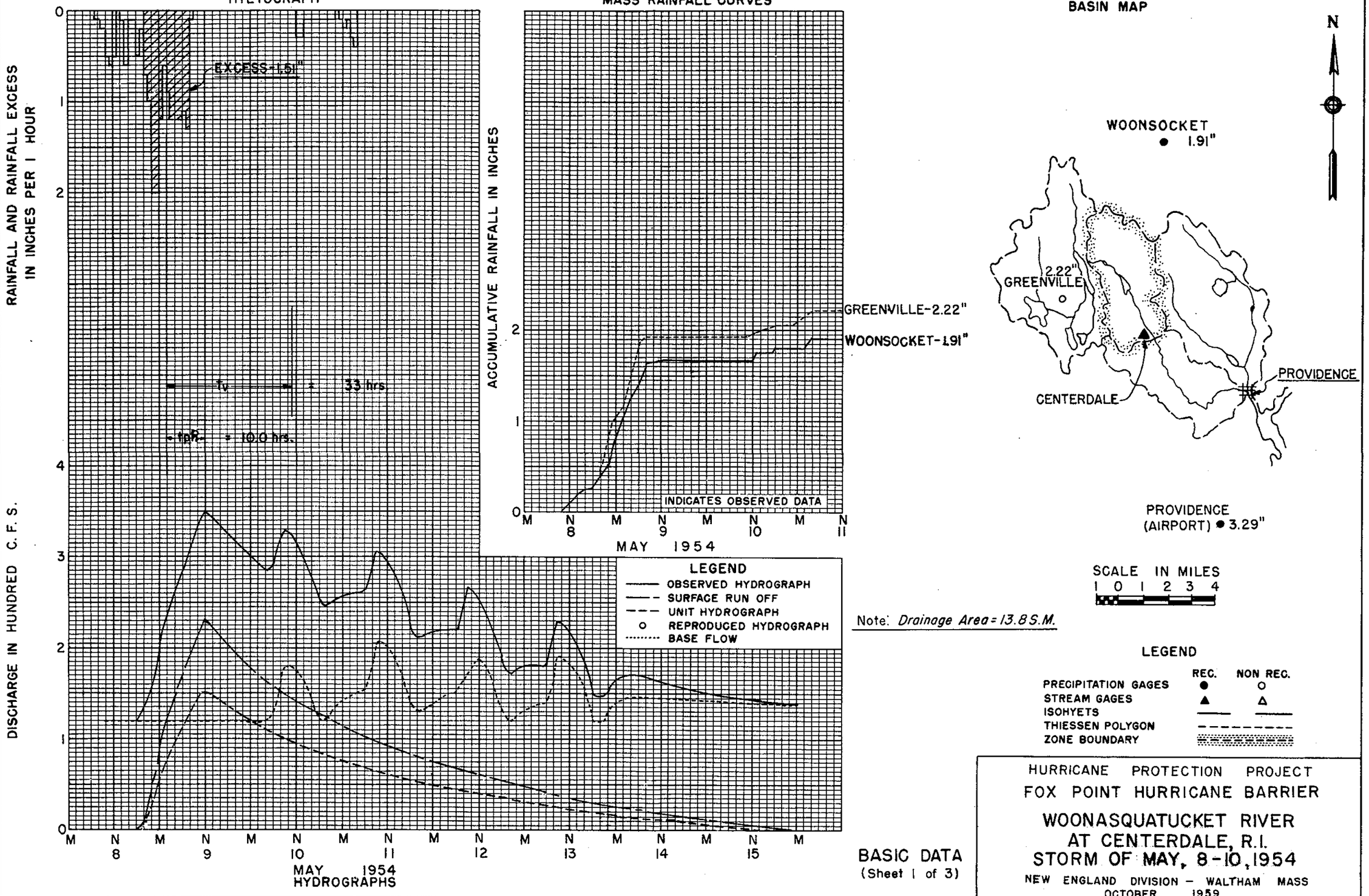
DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

HYETOGRAPH

MASS RAINFALL CURVES

BASIN MAP



Note: *Drainage Area = 13.8 S.M.*

LEGEND

	REC.	NON REC.
PRECIPITATION GAGES	●	○
STREAM GAGES	▲	△
ISOHYETS	——	——
THIESSEN POLYGON	- - - - - -	
ZONE BOUNDARY		

BASIC DATA
(Sheet 1 of 3)

HURRICANE PROTECTION PROJECT

FOX POINT HURRICANE BARRIER

WOONASQUATUCKET RIVER
AT CENTERDALE, R.I.
STORM OF MAY, 8-10, 1954

NEW ENGLAND DIVISION – WALTHAM MASS
OCTOBER 1959

ENG FORM 1822
1 NOV 49

PLATE NO. 2-7

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 2 OF 3)

(7) STREAM AND STATION Woodasquatucket River at Centerdale LAT 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM 8-11 May 1954 (9) OFFICE New England Division

(10) DRAINAGE AREA 13.8 SQ.MI. (11) L 6.40 MI. (12) L_{ca} 3.20 MI. (13) $(LL_{ca})^{0.3}$ 2.47

(14) AVERAGE RAINFALL 2.06 IN. (15) t_R 12 HRS. (16) DIRECT RUNOFF 1.51 IN.

(17) Q_{pR} 152 CFS. (18) q_{pR} 11.0 CFS/SQ.MI. (19) Q_p 172 CFS. (20) t_{pR} 10 HRS.

(21) t_p 10 HRS. (22) t_v 33 HRS. (23) C_{tR} 4.0 (24) C_{p640} 148 W_{50} 34 HRS. W_{75} 15 HRS.

TIME May 1954 (25)	OBSERVED DISCHARGE (~~1000~~ CFS) (26)	ESTIMATED BASE FLOW (~~1000~~ CFS) (27)	DIRECT RUNOFF (~~1000~~ CFS) (28)	12 HR UNIT HYDROGRAPH (~~1000~~ CFS) (29)	3 HR UNIT HYDROGRAPH (~~1000~~ CFS) (30)	REPRODUCED STORM HYDROGRAPH (~~1000~~ CFS) (31)	(32)	(33)
8-6P	120	120	0	0	0			
9	140	120	20	13	30			
M	200	120	80	53	70			
9-3A	250	120	130	86	132			
6	285	120	165	109	160			
9	325	120	205	136	172			
N	350	120	230	152	160			
3P	340	120	220	146	142			
6	325	120	205	136	126			
9	310	120	190	126	116			
M	300	120	180	119	108			
10-3A	290	120	170	113	102			
6	290	130	160	106	96			
9	330	180	150	99	91			
N	315	173	142	94	87			
3P	290	155	135	89	83			
6	250	122	128	85	78			
9	250	128	122	81	75			
M	258	142	116	77	71			
11-3A	260	150	110	73	68			
6	263	159	104	69	65			
9	305	206	99	66	61			
N	295	201	94	62	58			
3P	270	180	90	60	55			
6	228	142	86	57	52			
9	213	132	81	54	49			
M	218	141	77	51	47			
12-3A	222	149	73	48	44			
6	220	151	69	45	42			
9	267	202	65	43	40			
N	250	188	62	41	38			
3	228	170	58	38	36			
6	190	135	55	36	34			
9	172	120	52	34	32			
M	180	132	48	32	30			
13-3A	182	137	45	30	28			
6	182	140	42	28	27			
9	230	192	38	26	25			
N	218	183	35	25	24			
3P	197	165	32	23	22			

DATE 5/4/59 COMPUTED BY J.F. & AM

ENG FORM 1 NOV 49 1823

PLATE NO. 2-8

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 2 OF 3)

(7) STREAM AND STATION Woonasquatucket River at Centerdale LAT. 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM 8-11 May 1954 (9) OFFICE New England Division

(10) DRAINAGE AREA 13.8 SQ.MI. (11) L 6.40 MI. (12) L_{ca} 3.20 MI. (13) $(LL_{ca})^{0.3}$

(14) AVERAGE RAINFALL 2.06 IN. (15) t_R 12 HRS. (16) DIRECT RUNOFF 1.51 IN.

(17) Q_{pR} 152 CFS. (18) q_{pR} 11.0 CFS/SQ.MI. (19) Q_p 172 CFS. (20) t_{pR} 10 HRS.

(21) t_p 10 HRS. (22) t_v 33 HRS. (23) C_{tR} 4.0 (24) C_{p640} .148 W_{50} 34 HRS. W_{75} 15 HRS.

TIME May 1954 (25)	OBSERVED DISCHARGE (~~1000~~ CFS) (26)	ESTIMATED BASE FLOW (~~1000~~ CFS) (27)	DIRECT RUNOFF (~~1000~~ CFS) (28)	OBSERVED 12 HR UNIT HYDROGRAPH (~~1000~~ CFS) (29)	ADJUSTED 3 HR UNIT HYDROGRAPH (~~1000~~ CFS) (30)	REPRODUCED STORM HYDROGRAPH (~~1000~~ CFS) (31)	(32)	(33)
13-3P	197	165	32	23	22			
6	150	121	29	22	21			
9	148	121	27	20	19			
M	165	140	25	19	18			
14-3A	170	146	24	18	16			
6	170	148	22	16	15			
9	168	148	20	15	14			
N	164	146	18	13	12			
3P	161	145	16	12	11			
6	160	146	14	11	10			
9	158	145	13	10	9			
M	155	144	11	9	8			
15-3A	152	142	10	8	6			
6	150	142	8	7	5			
9	148	141	7	5	4			
N	146	140	6	4	3			
3P	144	139	5	3	1			
6	142	139	3	2	0			
9	140	138	2	1				
M	140	140	0	0				
Totals			423					

DATE COMPUTED BY

ENG FORM 1 NOV 49 1823

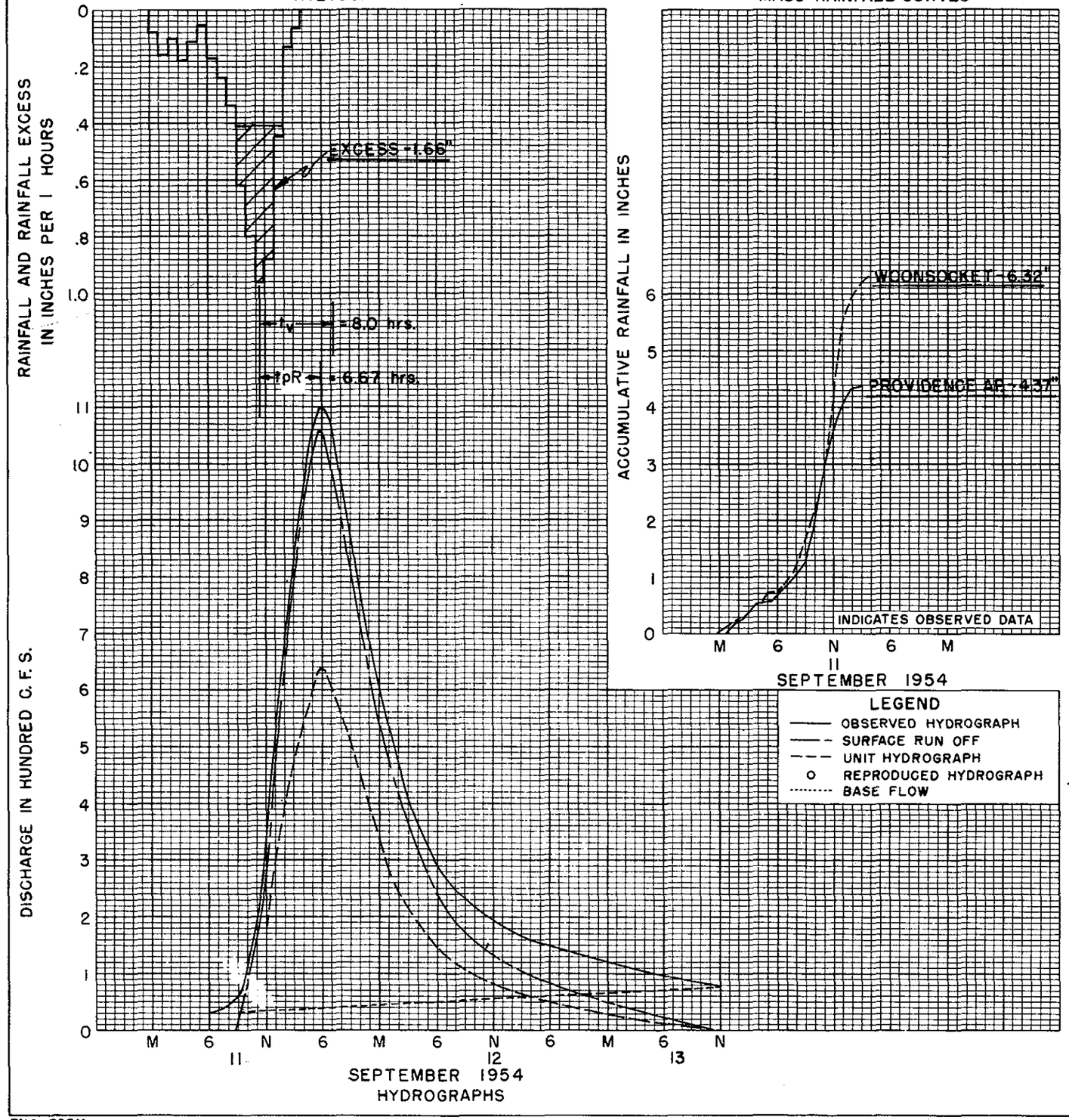
PLATE NO. 2-9

DEPARTMENT OF THE ARMY

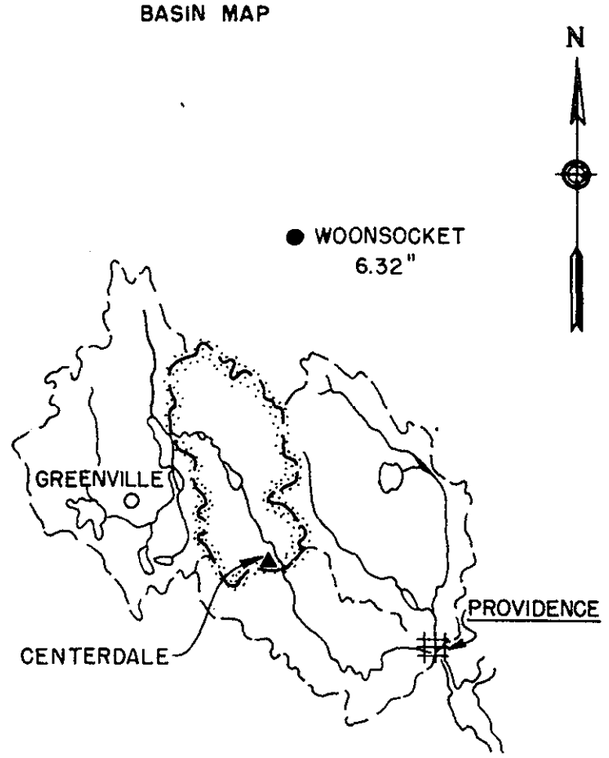
CORPS OF ENGINEERS

HYETOGRAPH

MASS RAINFALL CURVES



BASIN MAP



Note: *Drainage Area = 13.8 S.M.*

LEGEND

	REC.	NON REC.
PRECIPITATION GAGES	●	○
STREAM GAGES	▲	△
ISOHYETS	——	——
THIESSEN POLYGON	- - - - - - - -	
ZONE BOUNDARY		

BASIC DATA
(Sheet 1 of 2)

HURRICANE PROTECTION PROJECT

FOX POINT HURRICANE BARRIER

WOONASQUATUCKET RIVER
AT CENTERDALE, R.I.
STORM OF SEPT. 6, 1954

NEW ENGLAND DIVISION - WALTHAM MASS.
OCTOBER 1959

ENG FORM 1822
1 NOV 49

PLATE NO. 2-10

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 2 OF 2)

(7) STREAM AND STATION Woonasquatucket River at Centerdale LAT. 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM Sept. 11, 1954 (9) OFFICE New England Division

(10) DRAINAGE AREA 13.8 SQ.MI. (11) L 6.40 MI. (12) L_{ca} 3.20 MI. (13) $(LL_{ca})^{0.3}$ 2.47

(14) AVERAGE RAINFALL 5.34 IN. (15) t_R 5 HRS. (16) DIRECT RUNOFF 1.66 IN.

(17) Q_{pR} 637 CFS. (18) q_{pR} 46.2 CFS/SQ.MI. (19) Q_p 637 CFS. (20) t_{pR} 6.67 HRS.

(21) t_p 6.5 HRS. (22) t_v 8.0 HRS. (23) C_{tR} 337 (24) C_{p640} 460 W_{50} 13 HRS. W_{75} 7 HRS.

TIME September 1954 (25)	OBSERVED DISCHARGE (~~1000~~ CFS) (26)	ESTIMATED BASE FLOW (~~1000~~ CFS) (27)	DIRECT RUNOFF (~~1000~~ CFS) (28)	3 HR UNIT HYDROGRAPH (~~1000~~ CFS) (29)	ADJUSTED 3 HR UNIT HYDROGRAPH (~~1000~~ CFS) (30)	REPRODUCED STORM HYDROGRAPH (~~1000~~ CFS) (31)	(32)	(33)
11-6A	32	32	0	0	0			
9	56	35	21	13	13			
N	330	37	293	177	177			
3P	825	40	785	473	473			
6	1100	43	1057	637	637			
9	875	45	830	500	500			
M	605	48	557	337	337			
12-3A	410	51	359	218	218			
6	296	53	243	148	148			
9	231	56	175	107	107			
N	195	59	136	83	83			
3P	169	61	108	66	66			
6	150	64	86	52	52			
9	132	67	65	40	40			
M	120	69	51	31	31			
13-3A	109	72	37	22	22			
6	99	75	24	14	14			
9	88	77	11	6	6			
N	80	80	0	0	0			
Totals	5902	1064	4838	2924	2924			

DATE COMPUTED BY J. F. & A. M.

ENG FORM 1 NOV 49 1823

PLATE NO. 2-11

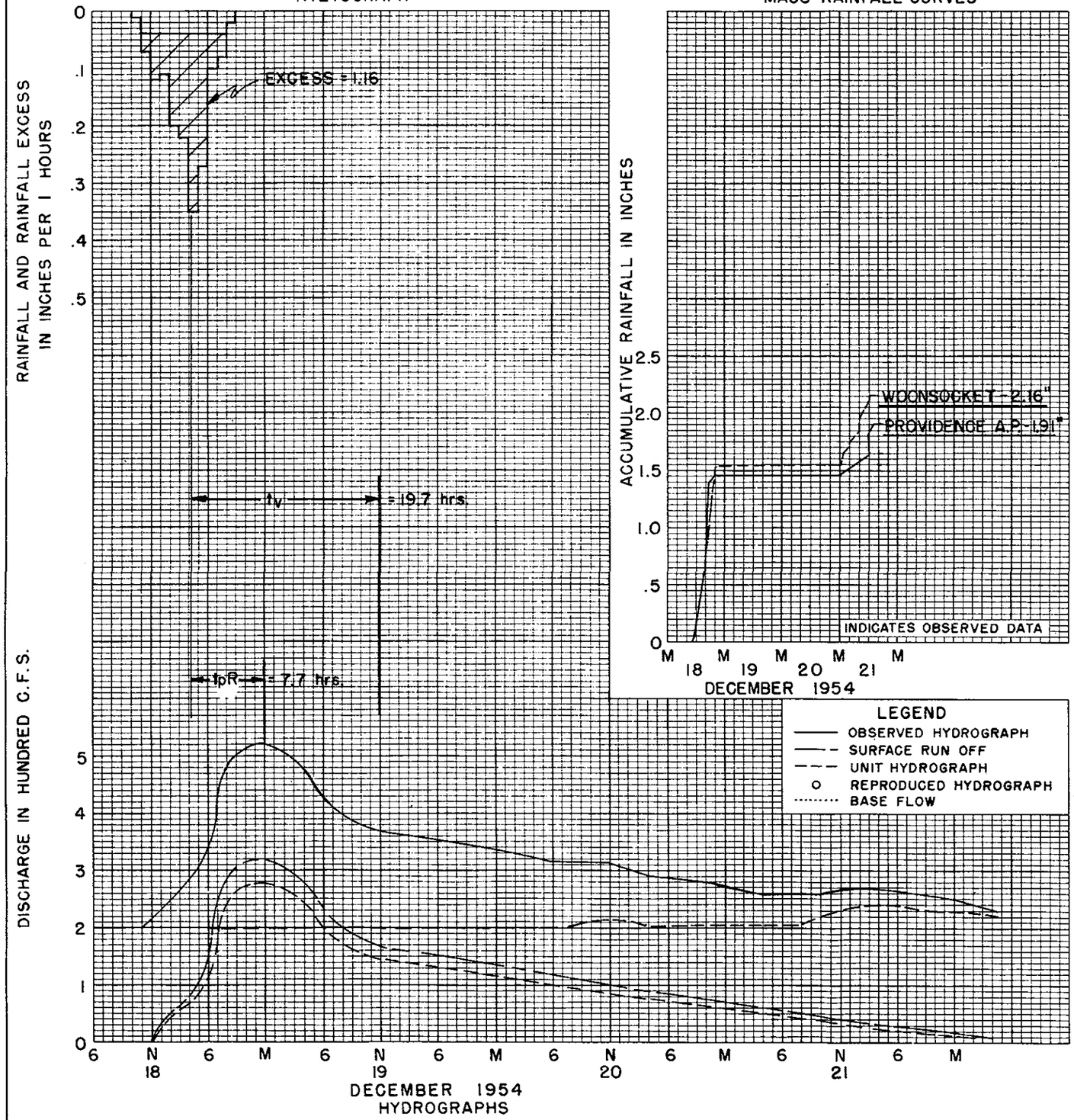
DEPARTMENT OF THE ARMY

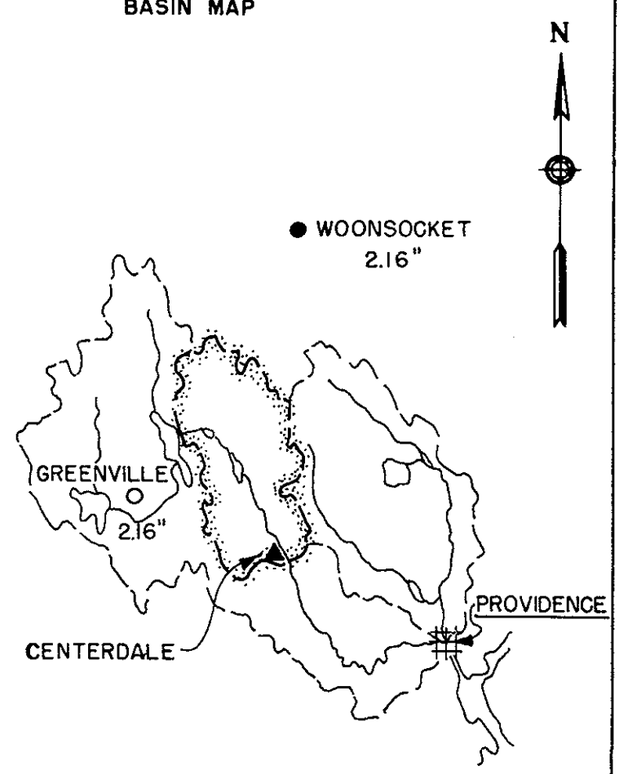
CORPS OF ENGINEERS

HYETOGRAPH

MASS RAINFALL CURVES

BASIN MAP





PROVIDENCE (AIRPORT) 1.91"

SCALE IN MILES
1 0 1 2 3 4

Note: *Drainage Area = 13.8 S.M.*

LEGEND

	REC.	NON REC.
PRECIPITATION GAGES	●	○
STREAM GAGES	▲	△
ISOHYETS	——	——
THIESSEN POLYGON	- - - - -	- - - - -
ZONE BOUNDARY	▒▒▒▒▒	▒▒▒▒▒

BASIC DATA
(Sheet 1 of 3)

HURRICANE PROTECTION PROJECT

FOX POINT HURRICANE BARRIER

WOONASQUATUCKET RIVER AT CENTERDALE, R.I. STORM OF DEC. 18-21, 1954

NEW ENGLAND DIVISION - WALTHAM MASS
OCTOBER 1959

ENG FORM 1 NOV 49 1822

PLATE NO. 2-12

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 2 OF 3 Sh)

(7) STREAM AND STATION Woonasquatucket River at Centerdale at 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM Dec 18-21 1954 (9) OFFICE New England Division

(10) DRAINAGE AREA 13.8 SQ.MI. (11) L 6.40 MI. (12) L_{ca} 3.20 MI. (13) $(LL_{ca})^{0.3}$ 2.47

(14) AVERAGE RAINFALL 2.16 IN. (15) t_R 9 HRS. (16) DIRECT RUNOFF 1.16 IN.

(17) Q_{pR} 276 CFS. (18) q_{pR} 20.0 CFS/SQ.MI. (19) Q_p 367 CFS. (20) t_{oR} 7.7 HRS.

(21) t_p 8.0 HRS. (22) t_v 19.7 HRS. (23) C_{tR} 3.37 (24) C_p 640 460 W_{50} 13 HRS. W_{75} 7 HRS.

TIME December 1954 (25)	OBSERVED DISCHARGE (~~1000~~ CFS) (26)	ESTIMATED BASE FLOW (~~1000~~ CFS) (27)	DIRECT RUNOFF (~~1000~~ CFS) (28)	OBSERVED 4 HR UNIT HYDROGRAPH (~~1000~~ CFS) (29)	ADJUSTED 3 HR UNIT HYDROGRAPH (~~1000~~ CFS) (30)	REPRODUCED STORM HYDROGRAPH (~~1000~~ CFS) (31)	(32)	(33)
18-10A	200	200	0	0	0			
N	210	200	10	9	22			
2P	255	200	55	47	69			
4	280	200	80	69	122			
6	335	200	135	116	187			
8	485	200	285	246	272			
10	515	200	315	272	*353			
M	520	200	320	276	355			
19-2A	510	200	310	267	298			
4	480	200	280	241	247			
6	430	200	230	198	207			
8	400	200	200	172	177			
10	380	200	180	155	158			
N	370	200	170	147	146			
2P	365	200	165	142	136			
4	360	200	160	138	126			
6	355	200	155	134	118			
8	350	200	150	129	111			
10	340	200	140	121	105			
M	335	200	135	116	99			
20-2A	330	200	130	112	93			
4	325	200	125	108	88			
6	320	200	120	103	83			
8	315	205	110	95	79			
10	315	210	105	91	73			
N	315	215	100	86	68			
2P	305	210	95	82	64			
4	295	205	90	78	60			
6	290	205	85	73	56			
8	285	205	80	69	52			
10	280	205	75	65	48			
M	275	205	70	60	44			
21-2A	265	200	65	56	40			
4	260	200	60	52	36			
6	260	205	55	47	33			
8	260	210	50	43	31			
10	260	215	45	39	27			
N	270	230	40	34	23			
2P	270	235	35	30	21			
4	270	240	30	26	18			

DATE COMPUTED BY

ENG FORM 1 NOV 49 1823

PLATE NO. 2-13

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS (SHEET 3 OF 3)

(7) STREAM AND STATION Woonasquatucket River at Centerdale LAT. 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM Dec 18-21 1954 (9) OFFICE New England Division

(10) DRAINAGE AREA 13.8 SQ.MI. (11) L 6.40 MI. (12) L_{ca} 3.20 MI. (13) $(LL_{ca})^{0.3}$ 2.47

(14) AVERAGE RAINFALL 2.16 IN. (15) t_R 9 HRS. (16) DIRECT RUNOFF 1.16 IN.

(17) Q_{pR} 276 CFS. (18) q_{pR} 20.0 CFS/SQ.MI. (19) Q_p 640 CFS. (20) t_{pR} 7.7 HRS.

(21) t_p 11.5 HRS. (22) t_v 19.7 HRS. (23) C_{tR} 3.37 (24) C_p 640 460 W_{50} 13 HRS. W_{75} 7 HRS.

TIME December 1954 (25)	OBSERVED DISCHARGE (~~1000 CFS~~) (26)	ESTIMATED BASE FLOW (~~1000 CFS~~) (27)	DIRECT RUNOFF (~~1000 CFS~~) (28)	OBSERVED 4 HR UNIT HYDROGRAPH (~~1000 CFS~~) (29)	ADJUSTED 3 HR UNIT HYDROGRAPH (~~1000 CFS~~) (30)	REPRODUCED STORM HYDROGRAPH (~~1000 CFS~~) (31)	(32)	(33)
21-4P	270	240	30	26	18			
6	265	239	26	22	15			
8	260	237	23	20	12			
10	255	235	20	17	9			
M	250	234	16	14	6			
22-2A	240	227	13	11	3			
4A	235	225	10	9	0			
Totals	14745	9597	5198	4437	4390			
*Peak								
11 PM					367			

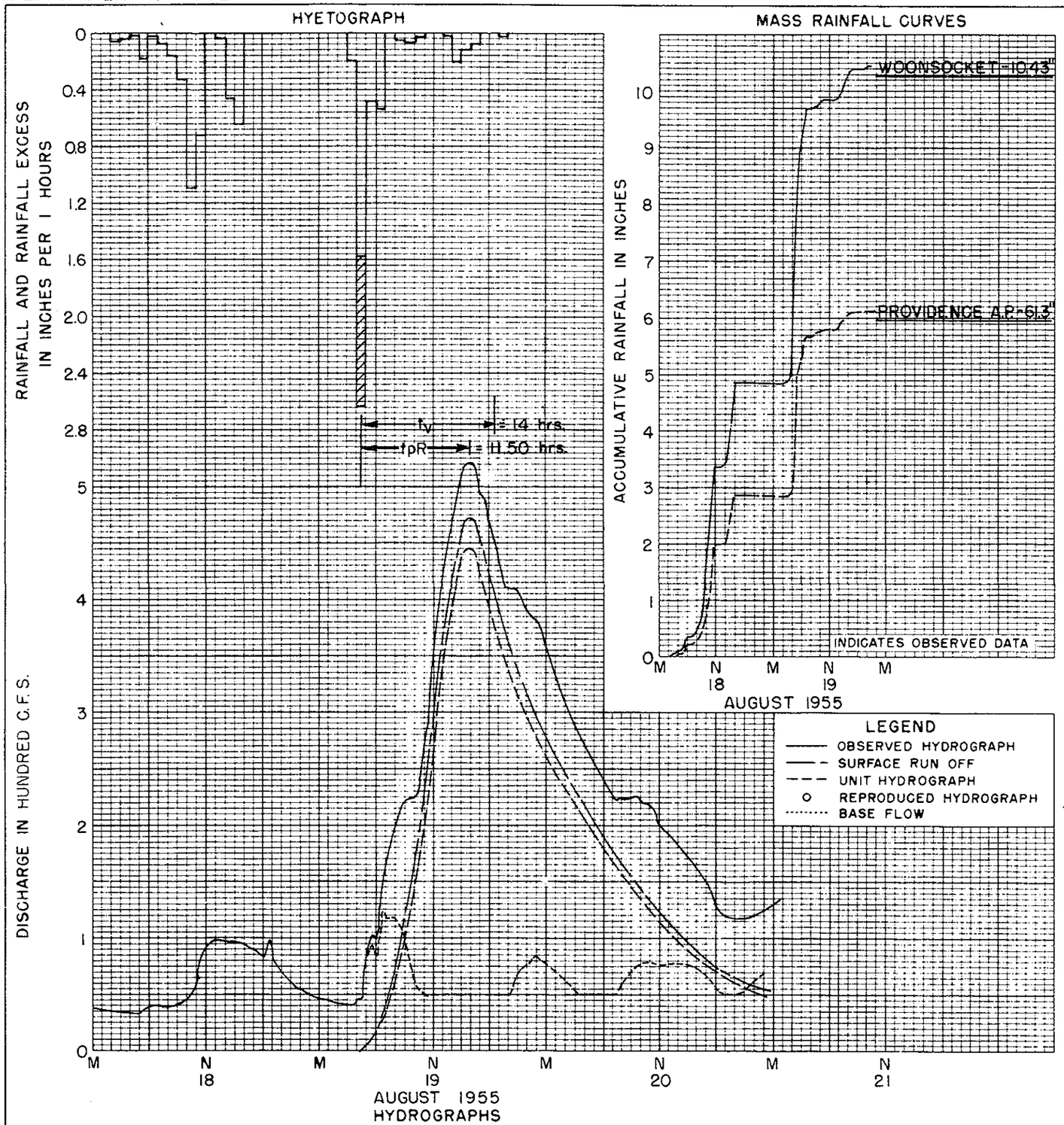
DATE COMPUTED BY

ENG FORM 1 NOV 49 1823

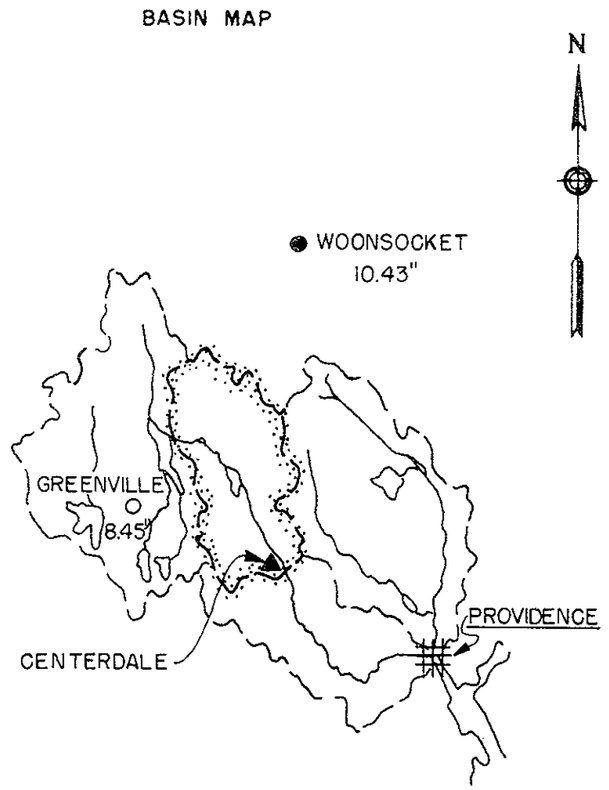
PLATE NO. 2-14

DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS



LEGEND
- OBSERVED HYDROGRAPH
- SURFACE RUN OFF
- UNIT HYDROGRAPH
- REPRODUCED HYDROGRAPH
- BASE FLOW



Note: *Drainage Area = 13.8 S.M.*

LEGEND

	REC.	NON REC.
PRECIPITATION GAGES	●	○
STREAM GAGES	▲	△
ISOHYETS	——	——
THIESSEN POLYGON	- - - - - -	- - - - - -
ZONE BOUNDARY	·-·-·-·-·	·-·-·-·-·

BASIC DATA
(Sheet 1 of 2)

HURRICANE PROTECTION PROJECT

FOX POINT HURRICANE BARRIER

WOONASQUATUCKET RIVER AT CENTERDALE, R.I. STORM OF AUG. 18-19 1955

NEW ENGLAND DIVISION - WALTHAM MASS.
OCTOBER 1959

ENG FORM 1822
1 NOV 49

PLATE NO. 2-15

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 2 OF 2)

(7) STREAM AND STATION Woonasquatucket River at Centerdale LAT. 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM August 18-19, 1955 (9) OFFICE New England Division

(10) DRAINAGE AREA 13.8 SQ.MI. (11) L 6.40 MI. (12) L_{ca} 3.20 MI. (13) $(LL_{ca})^{0.3}$ 2.47

(14) AVERAGE RAINFALL 8.28 IN. (15) t_R 1 HRS. (16) DIRECT RUNOFF 1.06 IN.

(17) Q_{pR} 445 CFS. (18) q_{pR} 32.25 CFS/SQ.MI. (19) Q_p 445 CFS. (20) t_{pR} 11.50 HRS.

(21) t_p 11.50 HRS. (22) t_v 14 HRS. (23) C_{tR} 4.66 (24) C_{p640} 380 W_{50} 16 HRS. W_{75} 7 HRS.

TIME August 1955 (25)	OBSERVED DISCHARGE (~~1000~~ CFS) (26)	ESTIMATED BASE FLOW (~~1000~~ CFS) (27)	DIRECT RUNOFF (~~1000~~ CFS) (28)	OBSERVED 1 HR UNIT HYDROGRAPH (~~1000~~ CFS) (29)	ADJUSTED 2 HR UNIT HYDROGRAPH (~~1000~~ CFS) (30)	REPRODUCED STORM HYDROGRAPH (~~1000~~ CFS) (31)	(32)	(33)
17-M	40	40	0	0	0			
18-3A	36	36	0	0	0			
6	41	41	0	0	0			
9	42	42	0	0	0			
N	96	96	0	0	0			
3P	98	98	0	0	0			
6	82	82	0	0	0			
9	62	62	0	0	0			
M	48	48	0	0	0			
19-3A	43	43	0	0	0			
6	100	80	20	19	8			
9	224	104	120	113	80			
N	360	50	310	292	220			
3P	*510	50	*460	*434	*390			
6	473	50	423	399	423			
9	408	73	335	316	340			
M	362	81	281	265	280			
20-3A	290	55	235	222	235			
6	243	50	193	183	195			
9	226	71	155	146	156			
N	202	77	125	118	127			
3P	172	77	95	90	103			
6	130	55	75	71	83			
9	118	53	65	61	67			
M	130	74	56	53	55			
21-3A	147	100	47	44	45			
6	170	130	40	38	38			
9	204	170	34	32	32			
N	226	200	26	25	26			
3P	235	215	20	19	21			
6	244	230	14	13	16			
9	229	220	9	8	12			
M	210	205	5	5	8			
22-3A	202	200	2	2	4			
6	200	200	0	0	0			
Totals	6603	3458	3145					
*Peak								
4P	522	50	472	445	445			
5P								

DATE 4-30-59 COMPUTED BY APM

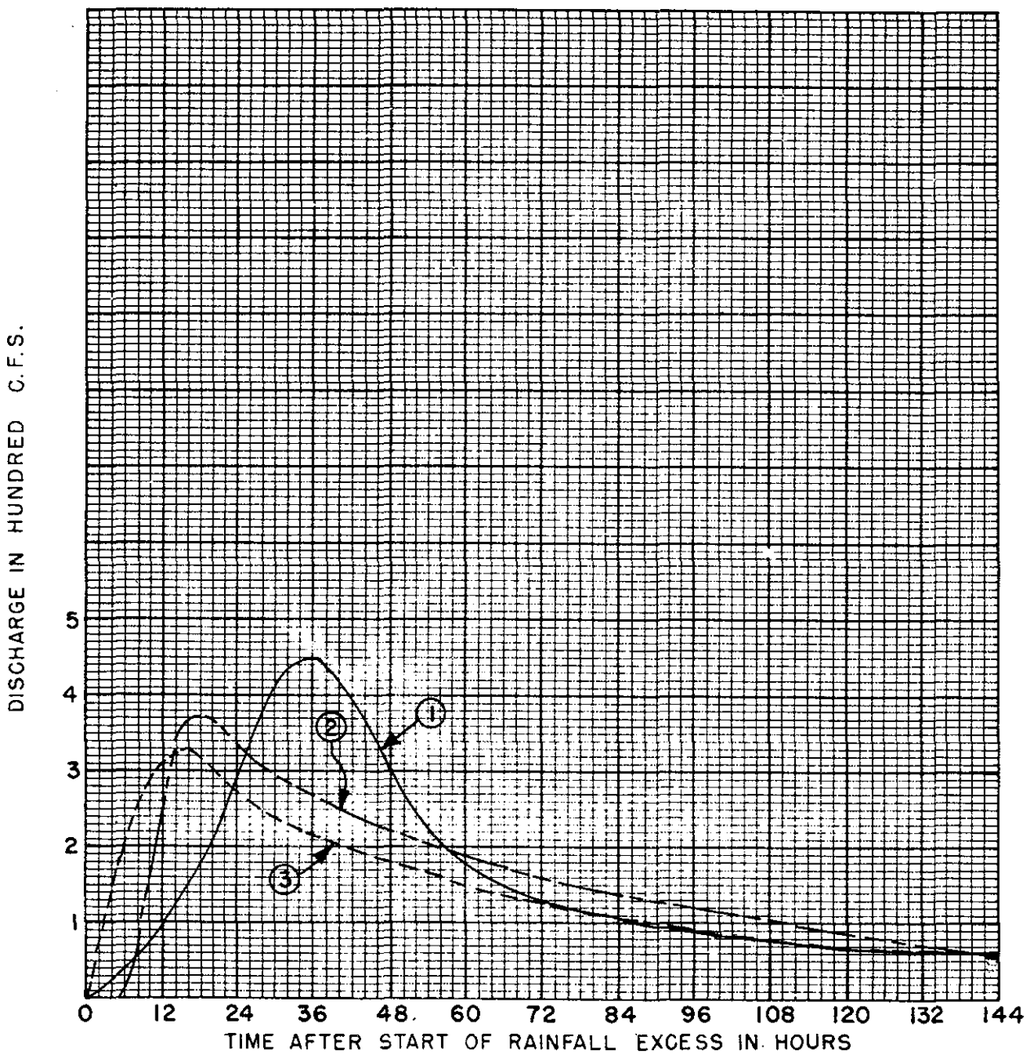
ENG FORM 1 NOV 49 1823

PLATE NO. 2-16

DEPARTMENT OF THE ARMY

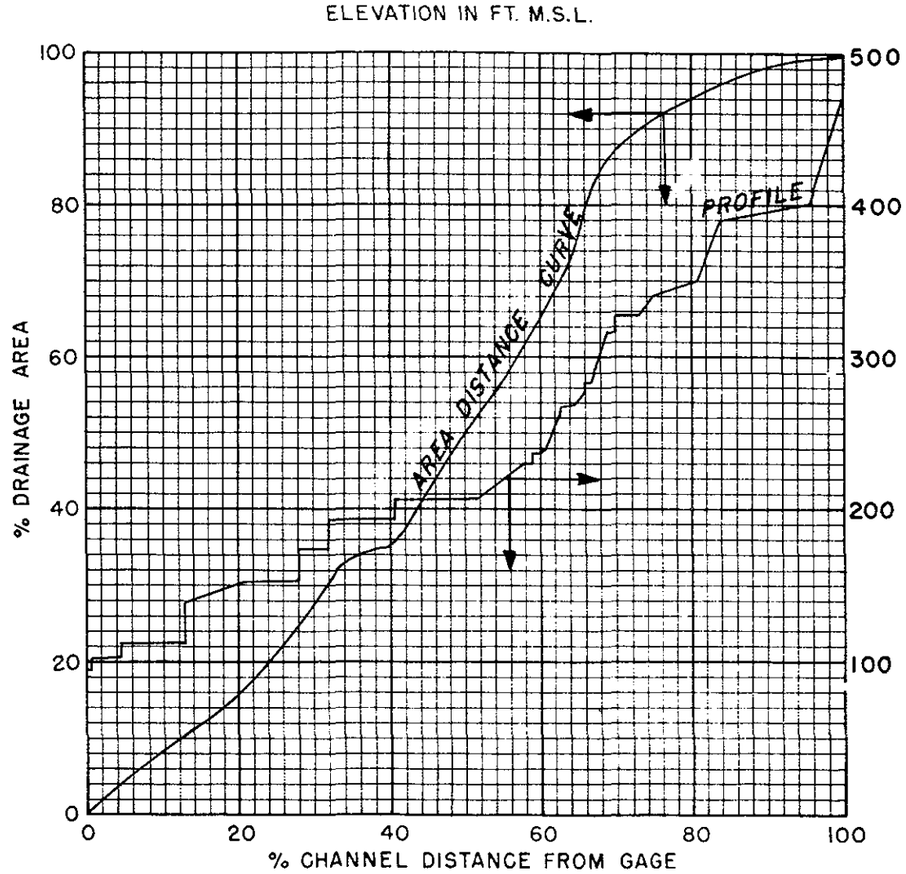
CORPS OF ENGINEERS

OBSERVED UNIT HYDROGRAPHS



DRAINAGE AREA CHARACTERISTICS

DRAINAGE AREA	38.3	sq.mi.	L	13.5	mi.
MAXIMUM ELEVATION	580	ft.m.s.l.	L_{ca}	5.5	mi.
MINIMUM ELEVATION	95	ft.m.s.l.	$(LL_{ca})^{0.3}$	3.64	
MEAN ELEVATION (weighted)		ft.m.s.l.	DRAINAGE DENSITY		mi/sq.mi.
LAND SLOPE		ft./mi.	MAP SCALE		
MAIN STREAM SLOPE	27.8	ft./mi.	METHOD OF FLOW SEPARATION		
			BASIN SHAPE FACTOR		



DATA FROM OBSERVED UNIT HYDROGRAPHS

DATE OF RAINFALL	LEGEND	AVE. P (In.)	RAINFALL EXCESS DURATION (hr.)	RAINFALL EXCESS AMOUNT (In.)	L_{cP} (mi.)	STAGE RECORD	Q_{pR} (cfs.)	Q_p $_{tr=}$ hrs. (cfs.)	t_{pR} (hr.)	t_p (hr.)	t_v (hr.)	C_{tR}	C_p640	K_m (hr.)	T_c (hr.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
OCT. 1955	——①	6.74	21	3.01		REC.	296	450	26.6						
NOV. 1955	----②	2.90	10	1.03		REC.	372	372	12.5						
APR. 1957	---③	3.35	8	.07		REC.	333	333	12.0						

Note: *Drainage Area = 38.3 S. M.*

HURRICANE PROTECTION PROJECT

FOX POINT HURRICANE BARRIER

WOONASQUATUCKET RIVER
AT CENTERDALE R.I.
UNIT HYDROGRAPHS PERTINENT DATA

NEW ENGLAND DIVISION — WALTHAM MASS.
OCTOBER 1959

ENG FORM 1 NOV 49 1821

PLATE NO. 2-17

DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

HYETOGRAPH

MASS RAINFALL CURVES

BASIN MAP

RAINFALL AND RAINFALL EXCESS IN INCHES PER 1 HOURS

ACCUMULATIVE RAINFALL IN INCHES

DISCHARGE IN HUNDRED C.F.S.

EXCESS - 3.01"

t_v = 47 hrs.

t_{pR} = 26.62 hrs.

GREENVILLE - 7.53"

WOONSOCKET - 5.95"

INDICATES OBSERVED DATA

OCTOBER 1955

LEGEND

OBSERVED HYDROGRAPH

SURFACE RUN OFF

UNIT HYDROGRAPH

REPRODUCED HYDROGRAPH

BASE FLOW

OCTOBER 1955 HYDROGRAPHS

WOONSOCKET 5.95"

7.53" GREENVILLE

PROVIDENCE

CENTERDALE

PROVIDENCE (AIRPORT) 4.08"

SCALE IN MILES 1 0 1 2 3 4

Note: *Drainage Area = 38.3 S.M.*

LEGEND

	REC.	NON REC.
PRECIPITATION GAGES	●	○
STREAM GAGES	▲	△
ISOHYETS	——	——
THIESSEN POLYGON	- - - - - - - -	
ZONE BOUNDARY		

BASIC DATA
(Sheet 1 of 3)

HURRICANE PROTECTION PROJECT

FOX POINT HURRICANE BARRIER

WOONASQUATUCKET RIVER AT CENTERDALE, R.I.
STORM OF OCT. 14-17, 1955

NEW ENGLAND DIVISION - WALTHAM MASS.
OCTOBER 1959

ENG FORM 1822
1 NOV 49

PLATE NO. 2-18

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 2 OF 23)

(7) STREAM AND STATION Woonasquatucket River at Centerdale 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM 14-17 October 1955 (9) OFFICE New England Division

(10) DRAINAGE AREA 38.3 SQ.MI. (11) L 13.5 MI. (12) L_{ca} 5.5 MI. (13) $(LL_{ca})^{0.3}$ 3.64

(14) AVERAGE RAINFALL 6.74 IN. (15) t_R 21 HRS. (16) DIRECT RUNOFF 3.01 IN.

(17) Q_{pR} 296 CFS. (18) q_{pR} 7.73 CFS/SQ.MI. (19) Q_p 450 CFS. (20) t_{pR} 26.62 HRS.

(21) t_p 30 HRS. (22) t_v 47 HRS. (23) C_{tR} 7.31 (24) C_{p640} 206 - W_{50} 33 HRS. W_{75} 20 HRS.

TIME October 1955 (25)	OBSERVED DISCHARGE ~~(1000 CFS)~~ (26)	ESTIMATED BASE FLOW ~~(1000 CFS)~~ (27)	DIRECT RUNOFF ~~(1000 CFS)~~ (28)	48 HR UNIT HYDROGRAPH ~~(1000 CFS)~~ (29)	12 HR UNIT HYDROGRAPH ~~(1000 CFS)~~ (30)	REPRODUCED STORM HYDROGRAPH ~~(1000 CFS)~~ (31)	(32)	(33)
14-M	72	50	22	7	0			
15-3A	84	51	33	11	20			
6	103	52	51	17	43			
9	148	53	95	32	70			
N	202	53	149	50	100			
3P	258	54	204	68	140			
6	325	55	270	90	180			
9	400	56	344	115	235			
M	480	57	423	141	300			
16-3A	540	58	482	161	360			
6	602	58	544	181	400			
9	676	59	617	206	440			
N	753	60	693	231	450			
3P	830	61	769	256	430			
6	905	62	843	281	395			
9	950	63	887	296	355			
M	910	63	847	282	305			
17-3A	895	131	764	255	260			
6	956	266	690	230	225			
9	948	318	630	210	200			
N	910	330	580	193	180			
3P	860	310	550	183	163			
6	812	305	507	167	150			
9	760	285	475	118	191			
M	716	266	450	150	133			
18-3A	676	251	425	142	126			
6	643	243	400	133	119			
9	610	225	385	128	113			
N	580	213	367	122	108			
3P	552	202	350	111	103			
6	526	191	335	112	97			
9	503	178	325	108	93			
M	487	177	310	103	89			
19-3A	465	165	300	100	86			
6	450	160	290	97	83			
9	435	155	280	93	80			
N	420	150	270	90	76			
3P	403	141	262	87	73			
6	375	120	255	85	70			
9	366	121	245	82	67			

DATE COMPUTED BY

ENG FORM 1 NOV 49 1823

PLATE NO. 2-19

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 3 OF 3)

(7) STREAM AND STATION Woonasquatucket River at Centerdale 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM 14-17 October 1955 (9) OFFICE New England Division

(10) DRAINAGE AREA 38.3 SQ.MI. (11) L 13.5 MI. (12) L_{ca} 5.5 MI. (13) $(LL_{ca})^{0.3}$ 3.64

(14) AVERAGE RAINFALL 6.74 IN. (15) t_R 21 HRS. (16) DIRECT RUNOFF 3.01 IN.

(17) Q_{pR} 296 CFS. (18) q_{pR} 7.73 CFS/SQ.MI. (19) Q_p 450 CFS. (20) t_{pR} 26.62 HRS.

(21) t_p 23 HRS. (22) t_v 47 HRS. (23) C_{tR} 7.31 (24) C_{p640} 206 W_{50} 33 HRS. W_{75} 20 HRS.

TIME October 1955 (25)	OBSERVED DISCHARGE ~~(1000 CFS)~~ (26)	ESTIMATED BASE FLOW ~~(1000 CFS)~~ (27)	DIRECT RUNOFF ~~(1000 CFS)~~ (28)	48 HR UNIT HYDROGRAPH ~~(1000 CFS)~~ (29)	12 HR UNIT HYDROGRAPH ~~(1000 CFS)~~ (30)	REPRODUCED STORM HYDROGRAPH ~~(1000 CFS)~~ (31)	(32)	(33)
19-9P	366	121	245	82	67			
M	358	118	240	80	65			
20-3A	348	118	230	77	63			
6	338	113	225	75	60			
9	329	109	220	73	57			
N	320	110	210	70	54			
3P	310	105	205	68	52			
6	300	100	200	67	50			
9	291	96	195	65	48			
M	282	92	190	63	46			
21-3A	278	93	185	62	44			
6	275	94	181	60	42			
9	272	95	177	59	40			
N	269	95	174	58	38			
3P	265	94	171	57	36			
6	262	95	167	56	34			
9	259	96	163	54	32			
M	256	97	159	53	30			
22-3A	250	98	152	51	29			
6	244	98	146	49	28			
9	238	99	139	46	26			
N	233	100	133	44	25			
3P	227	100	127	42	24			
6	221	101	120	40	23			
9	215	101	114	38	22			
M	210	101	109	36	20			
23-3A	208	102	106	35	18			
6	207	102	105	35	17			
9	206	102	104	35	16			
N	205	103	102	34	15			
3P	203	103	100	33	14			
6	202	103	99	33	13			
9	201	104	97	32	12			
M	200	104	96	32	10			
Totals	31068	9209	21859	7284	8161			

DATE COMPUTED BY

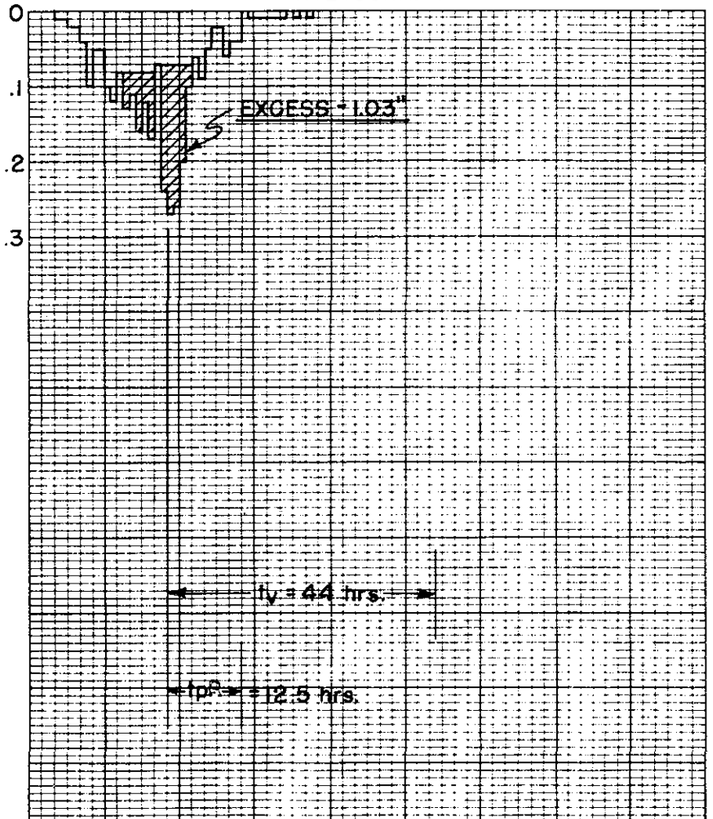
ENG FORM 1 NOV 49 1823

PLATE NO. 2-20

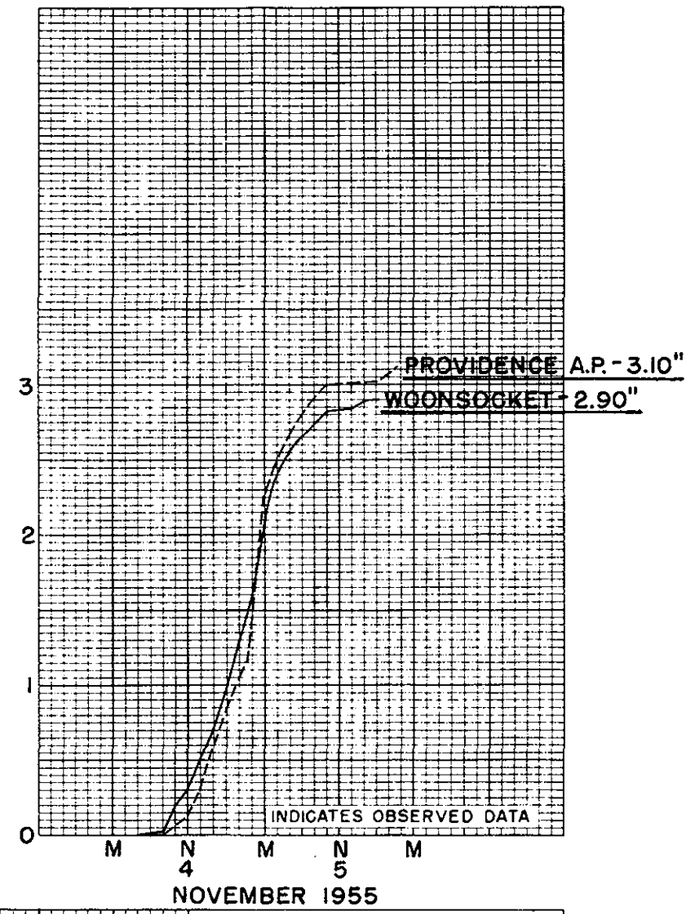
DEPARTMENT OF THE ARMY

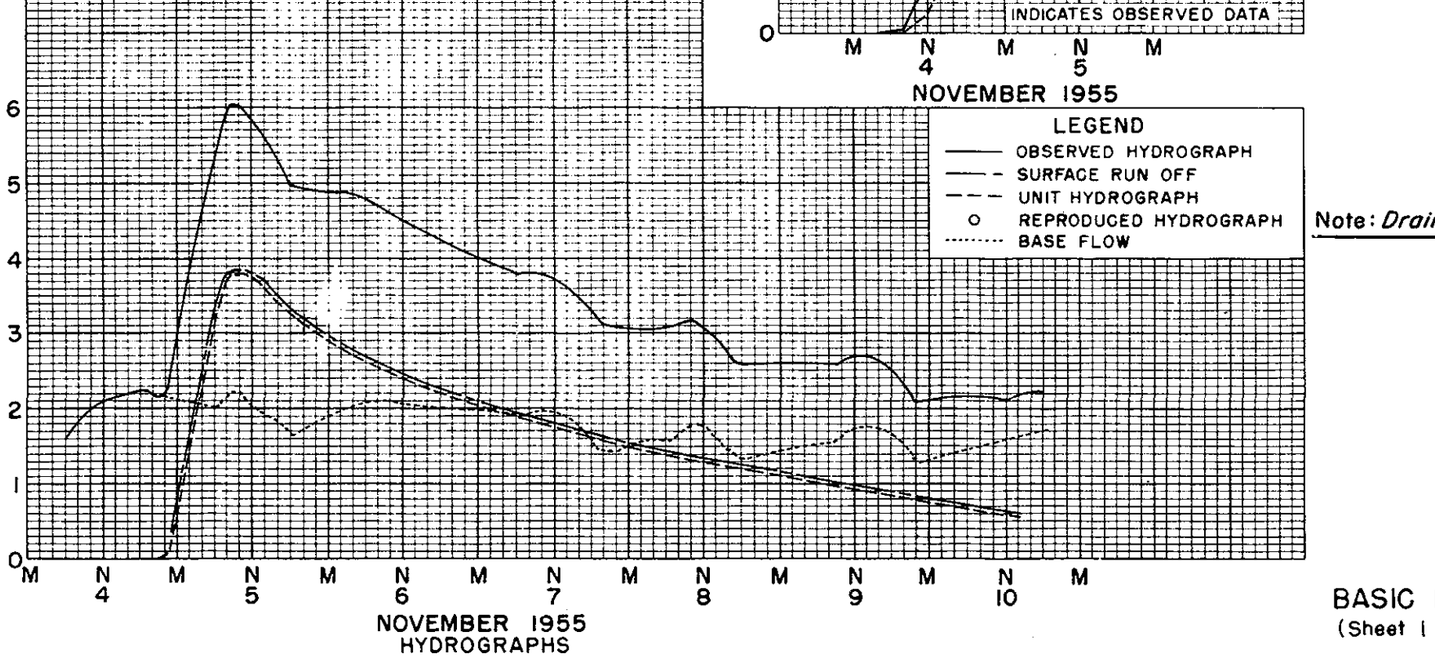
CORPS OF ENGINEERS

HYETOGRAPH

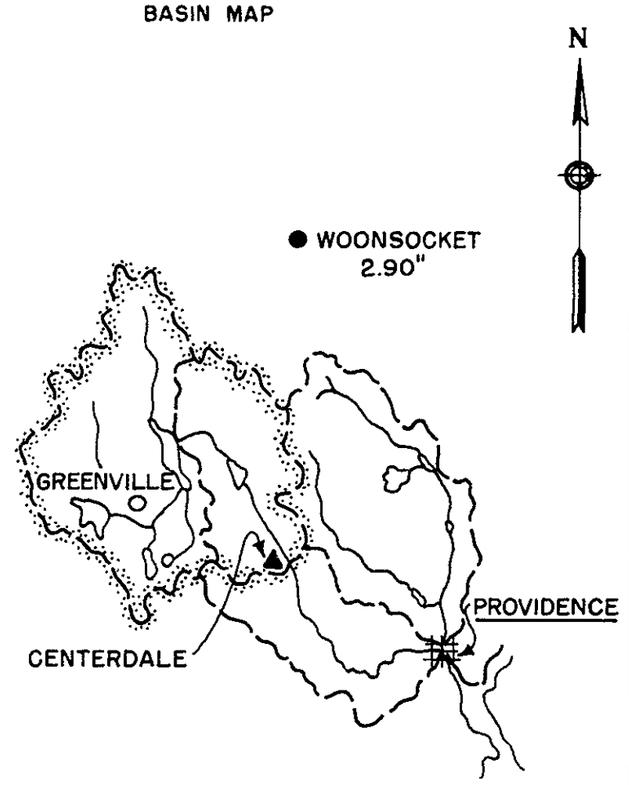


MASS RAINFALL CURVES





BASIN MAP



Note: *Drainage Area = 38.3 S.M.*

LEGEND

	REC.	NON REC.
PRECIPITATION GAGES	●	○
STREAM GAGES	▲	△
ISOHYETS	——	——
THIESSEN POLYGON	- - - - - -	
ZONE BOUNDARY	≈≈≈≈≈≈	

BASIC DATA
(Sheet 1 of 3)

HURRICANE PROTECTION PROJECT

FOX POINT HURRICANE BARRIER

WOONASQUATUCKET RIVER
AT CENTERDALE, R.I.
STORM OF NOV. 4-5, 1955

NEW ENGLAND DIVISION — WALTHAM MASS.
OCTOBER 1959

ENG FORM 1 NOV 49 1822

PLATE NO. 2-21

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 2 OF 23)

(7) STREAM AND STATION Woonasquatucket River at Centerdale LAT. 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM Nov. 3-5 1955 (9) OFFICE New England Division

(10) DRAINAGE AREA 38.3 SQ.MI. (11) L 13.5 MI. (12) L_{ca} 5.5 MI. (13) $(LL_{ca})^{0.3}$ 3.64

(14) AVERAGE RAINFALL 2.90 IN. (15) t_R 10 HRS. (16) DIRECT RUNOFF 1.03 IN.

(17) Q_{pR} 372 CFS. (18) q_{pR} 9.71 CFS/SQ.MI. (19) Q_p 372 CFS. (20) t_{pR} 12.5 HRS.

(21) t_p 11 HRS. (22) t_v 44 HRS. (23) C_{tR} 3.43 (24) C_{p640} 1020 W_{50} 50 HRS. W_{75} 21 HRS.

TIME November 1955 (25)	OBSERVED DISCHARGE ~~(1000-CFS)~~ (26)	ESTIMATED BASE FLOW ~~(1000-CFS)~~ (27)	DIRECT RUNOFF ~~(1000-CFS)~~ (28)	OBSERVED 4 HR UNIT HYDROGRAPH ~~(1000-CFS)~~ (29)	ADJUSTED 4 HR UNIT HYDROGRAPH ~~(1000-CFS)~~ (30)	REPRODUCED STORM HYDROGRAPH ~~(1000-CFS)~~ (31)	(32)	(33)
4 - 4A	160	160	0	0	0			
6	160	160	0	0	0			
8	183	183	0	0	0			
10	200	200	0	0	0			
N	210	210	0	0	0			
2P	215	215	0	0	0			
4	220	220	0	0	0			
6	225	225	0	0	0			
8	216	216	0	0	0			
10	220	212	8	8	8			
M	290	210	80	77	77			
5 - 2A	380	208	178	167	167			
4	465	205	260	252	252			
6	535	201	334	324	324			
8	600	217	383	372	372			
10	600	217	383	372	372			
N	585	202	383	372	372			
2P	560	190	370	359	359			
4	530	183	347	337	337			
6	493	161	332	322	322			
8	490	175	315	306	306			
10	487	182	305	296	296			
M	485	191	294	285	285			
6 - 2A	483	197	286	277	277			
4	481	203	278	270	270			
6	477	210	267	259	259			
8	468	208	260	252	252			
10	460	210	250	244	244			
N	450	205	245	238	238			
2P	440	201	239	232	232			
4	432	202	230	223	223			
6	425	200	225	218	218			
8	415	198	217	210	210			
10	407	196	211	205	205			
M	400	195	205	199	199			
7 - 2A	393	193	200	194	194			
4	386	191	195	189	189			
6	375	185	190	184	184			
8	378	193	185	179	179			
10	377	197	180	175	175			

DATE COMPUTED BY

ENG FORM 1 NOV 49 1823

PLATE NO. 2-22

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 2 OF 3)

(7) STREAM AND STATION Woonasquatucket River at Centerdale LAT. 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM Nov. 3-5 1955 (9) OFFICE New England Division

(10) DRAINAGE AREA 38.3 SQ.MI. (11) L 13.5 MI. (12) L_{ca} 5.5 MI. (13) $(LL_{ca})^{0.3}$ 3.64

(14) AVERAGE RAINFALL 2.90 IN. (15) t_R 42 HRS. (16) DIRECT RUNOFF 1.03 IN.

(17) Q_{pR} 372 CFS. (18) q_{pR} 9.71 CFS/SQ.MI. (19) Q_p 390 CFS. (20) t_{pR} 12.5 HRS.

(21) t_p 10 HRS. (22) t_v 44 HRS. (23) C_{tR} 3.43 (24) C_{p640} 1020 W_{50} 50 HRS. W_{75} 21 HRS.

TIME (25)	OBSERVED DISCHARGE (~~1000-CFS~~) (26)	ESTIMATED BASE FLOW (~~1000-CFS~~) (27)	DIRECT RUNOFF (~~1000-CFS~~) (28)	OBSERVED 4 HR UNIT HYDROGRAPH (~~1000 CFS~~) (29)	ADJUSTED 4 HR UNIT HYDROGRAPH (~~1000 CFS~~) (30)	REPRODUCED STORM HYDROGRAPH (~~1000 CFS~~) (31)	(32)	(33)
7 - N	368	193	175	170	170			
2P	357	187	170	165	165			
4	345	177	168	163	163			
6	318	154	164	159	159			
8	304	144	160	155	155			
10	302	146	156	151	151			
M	304	151	153	148	148			
8 - 2A	305	158	147	143	143			
4	303	158	145	141	141			
6	300	158	142	138	138			
8	310	170	140	136	136			
10	316	180	136	132	132			
N	307	174	133	129	129			
2P	290	160	130	126	126			
4	269	142	127	123	123			
6	258	133	125	131	131			
8	258	136	122	118	118			
10	258	140	118	114	114			
M	258	143	115	112	112			
9 - 2A	258	146	112	109	109			
4	257	149	108	105	105			
6	257	152	105	102	102			
8	256	155	101	98	98			
10	262	164	98	95	95			
N	270	175	95	92	92			
2P	270	178	92	89	89			
4	265	176	89	86	86			
6	250	165	85	82	82			
8	230	148	82	80	80			
10	206	127	79	77	77			
M	210	133	77	75	75			
10 - 2A	213	138	75	73	73			
4	214	141	73	71	71			
6	214	144	70	68	68			
8	215	148	67	65	65			
10	216	152	64	62	62			
N	217	157	60	58	58			
Totals	25766	13679	12087	11728	11728			

DATE COMPUTED BY

ENG FORM 1 NOV 49 1823

PLATE NO. 2-23

DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

HYETOGRAPH

RAINFALL AND RAINFALL EXCESS IN INCHES PER / HOURS

0 .1 .2

EXCESS-0.7"

t_y = 33 hrs.

t_{pR} = 12.07 hrs.

DISCHARGE IN HUNDRED C.F.S.

0 1 2 3 4 5

M 4 N M 5 N M 6 N M 7 N M 8 N M 9 N M 10 N M 11 N

APRIL 1957

HYDROGRAPHS

MASS RAINFALL CURVES

ACCUMULATIVE RAINFALL IN INCHES

0 1 2 3 4

Prov.

2.4"

INDICATES OBSERVED DATA

M 4 M 5 M 6 M 7 M 8 M 9 M

APRIL 1957

LEGEND

OBSERVED HYDROGRAPH

SURFACE RUN OFF

UNIT HYDROGRAPH

REPRODUCED HYDROGRAPH

BASE FLOW

PROVIDENCE A.P.-3.23"

WOONSOCKET-3.21"

BASIN MAP

N

WOONSOCKET 3.21"

3.48" GREENVILLE

CENTERDALE

PROVIDENCE

PROVIDENCE (AIRPORT) 3.23"

SCALE IN MILES

1 0 1 2 3 4

Note: *Drainage Area = 38.3 S.M.*

LEGEND

	REC.	NON REC.
PRECIPITATION GAGES	●	○
STREAM GAGES	▲	△
ISOHYETS	——	——
THIESSEN POLYGON	- - - - - -	
ZONE BOUNDARY		

BASIC DATA

(Sheet 1 of 3)

HURRICANE PROTECTION PROJECT

FOX POINT HURRICANE BARRIER

WOONASQUATUCKET RIVER AT CENTERDALE, R.I.

STORM OF APRIL 4-9, 1957

NEW ENGLAND DIVISION — WALTHAM MASS.

OCTOBER 1959

ENG FORM 1822
1 NOV 49

PLATE NO. 2-24

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS

(SHEET 2 OF 3)

(7) STREAM AND STATION Woonasquatucket River at Centerdale LAT. 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM 4-9 April 1957 (9) OFFICE New England Division

(10) DRAINAGE AREA 38.3 SQ.MI. (11) L 13.5 MI. (12) L_{ca} 5.5 MI. (13) $(LL_{ca})^{0.3}$ 3.64

(14) AVERAGE RAINFALL 3.35 IN. (15) t_R 8 HRS. (16) DIRECT RUNOFF 0.7 IN.

(17) Q_{pR} 333 CFS. (18) q_{pR} 8.69 CFS/SQ.MI. (19) Q_D 333 CFS. (20) t_{pR} 12.07 HRS.

(21) t_p 12 HRS. (22) t_v 33 HRS. (23) C_{tR} 3.32 (24) C_{p640} 105 W_{50} 48 HRS. W_{75} 20 HRS.

TIME Apr 1 1957 (25)	OBSERVED DISCHARGE (~~1000~~ CFS) (26)	ESTIMATED BASE FLOW (~~1000~~ CFS) (27)	DIRECT RUNOFF .7" R.O. (~~1000~~ CFS) (28)	OBSERVED 6 HR UNIT HYDROGRAPH (~~1000~~ CFS) (29)	ADJUSTED 6 HR UNIT HYDROGRAPH (~~1000~~ CFS) (30)	REPRODUCED STORM HYDROGRAPH (~~1000~~ CFS) (31)	(32)	(33)
4-6P	120	120	0	0	0			
9	115	115	0	0	0			
M	113	113	0	0	0			
5-3A	114	114	0	0	0			
6	120	120	0	0	0			
9	133	133	0	0	0			
N	165	165	0	0	0			
3P	188	188	0	0	0			
6	206	206	0	0	0			
9	239	214	25	36	36			
M	331	239	92	132	132			
6-3A	383	219	164	235	235			
6	467	263	204	291	291			
9	447	223	224	320	320			
N	451	218	233	333	333			
3P	431	213	218	312	312			
6	380	180	200	286	286			
9	378	191	187	267	267			
M	378	203	175	250	250			
7-3A	378	213	165	236	236			
6	369	212	157	225	225			
9	356	206	150	215	215			
N	344	201	143	205	205			
3P	332	196	136	194	194			
6	315	185	130	186	186			
9	313	188	125	179	179			
M	306	186	120	172	172			
8-3A	295	182	113	162	162			
6	287	178	109	156	156			
9	279	174	105	150	150			
N	276	176	100	143	143			
3P	279	184	95	136	136			
6	292	201	91	130	130			
9	300	212	88	126	126			
M	305	220	85	122	122			
9-3A	325	244	81	116	116			
6	338	261	77	110	110			
9	456	382	74	106	106			
N	363	293	70	100	100			
3P	352	284	68	97	97			

DATE 5/3/59 COMPUTED BY J. F. & A. M.

ENG FORM 1 NOV 49 1823

PLATE NO. 2-25

DEPARTMENT OF THE ARMY

UNIT HYDROGRAPH BASIC DATA SHEET

CORPS OF ENGINEERS (SHEET 3 OF)

(7) STREAM AND STATION Woonasquatucket River at Centerdale LAT. 41°-51'-32" LONG. 71°-29'-16"

(8) DATE OF STORM 4-9 April 1957 (9) OFFICE New England Division

(10) DRAINAGE AREA 38.3 SQ.MI. (11) L 13.5 MI. (12) L_{ca} 5.5 MI. (13) $(LL_{ca})^{0.3}$ 3.64

(14) AVERAGE RAINFALL 3.35 IN. (15) t_R 8 HRS. (16) DIRECT RUNOFF .7 IN.

(17) Q_{pR} 333 CFS. (18) q_{pR} 8.69 CFS/SQ.MI. (19) Q_p 333 CFS. (20) t_{pR} 12.07 HRS.

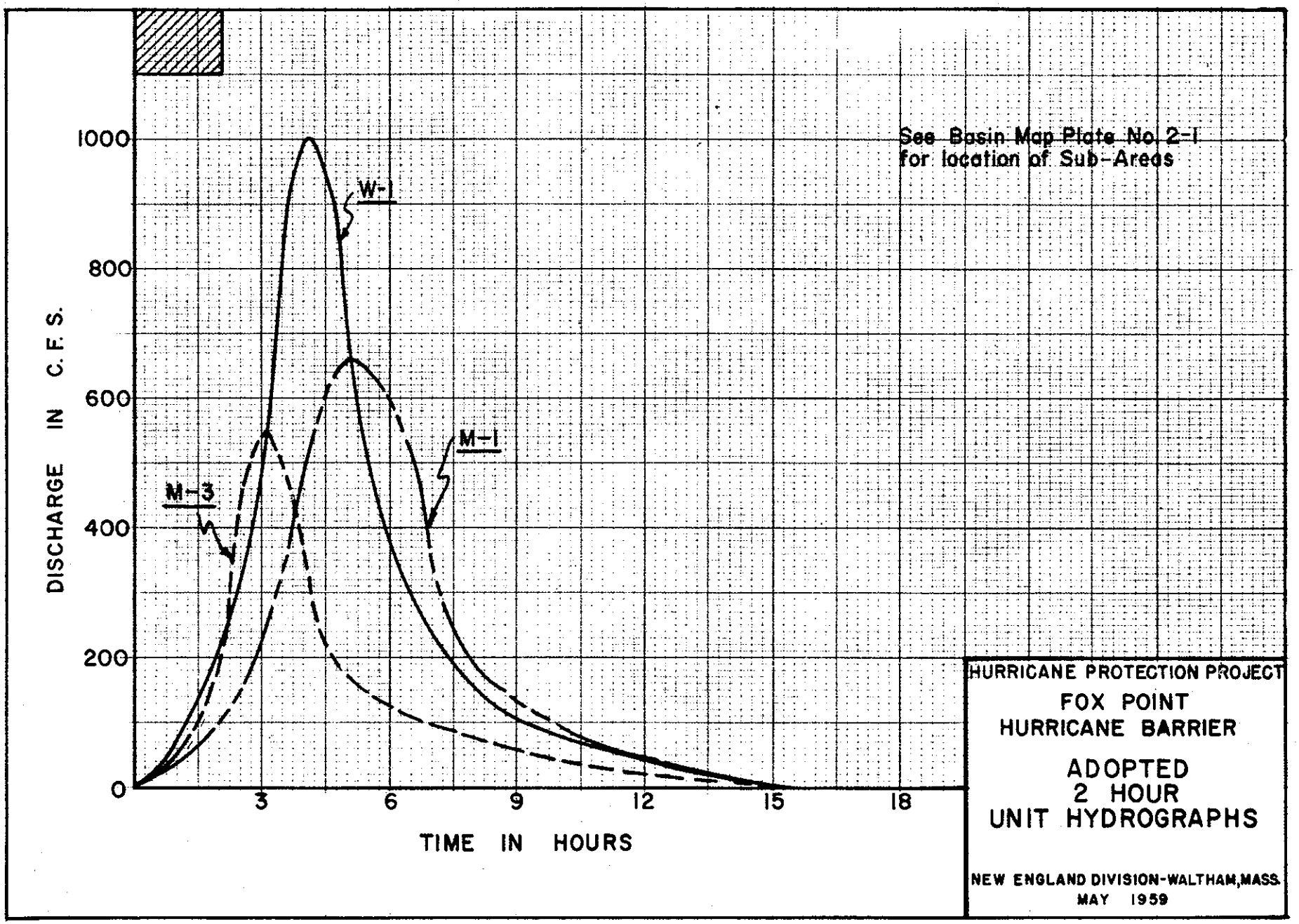
(21) t_p 12 HRS. (22) t_v 33 HRS. (23) C_{tR} 3.32 (24) C_{p640} 105 W_{50} 48 HRS. W_{75} 20 HRS.

TIME April 1957 (25)	OBSERVED DISCHARGE (~~1000~~ CFS) (26)	ESTIMATED BASE FLOW (~~1000~~ CFS) (27)	DIRECT RUNOFF .7" R.O. (~~1000~~ CFS) (28)	OBSERVED 6 HR UNIT HYDROGRAPH (~~1000~~ CFS) (29)	ADJUSTED 6 HR UNIT HYDROGRAPH (~~1000~~ CFS) (30)	REPRODUCED STORM HYDROGRAPH (~~1000~~ CFS) (31)	(32)	(33)
9-6P	337	272	65	93	93			
9	322	259	63	90	90			
M	316	255	61	87	87			
10-3A	303	245	58	83	83			
6	295	239	56	80	80			
9	295	241	54	77	77			
N	295	242	53	76	76			
3P	292	241	51	73	73			
6	290	241	49	70	70			
9	285	238	47	67	67			
M	281	236	45	64	64			
11-3A	276	232	44	63	63			
6	266	223	43	61	61			
9	258	216	42	60	60			
N	250	209	41	59	59			
3P	244	204	40	57	57			
6	238	199	39	56	56			
9	234	197	37	53	53			
M	230	194	36	51	51			
Totals	17326	12398	4928	7048	7048			

DATE COMPUTED BY

ENG FORM 1 NOV 49 1823

PLATE NO. 2-26



HURRICANE PROTECTION PROJECT

FOX POINT
HURRICANE BARRIER

ADOPTED
2 HOUR
UNIT HYDROGRAPHS

NEW ENGLAND DIVISION-WALTHAM, MASS.
MAY 1959

PLATE NO. 2-27

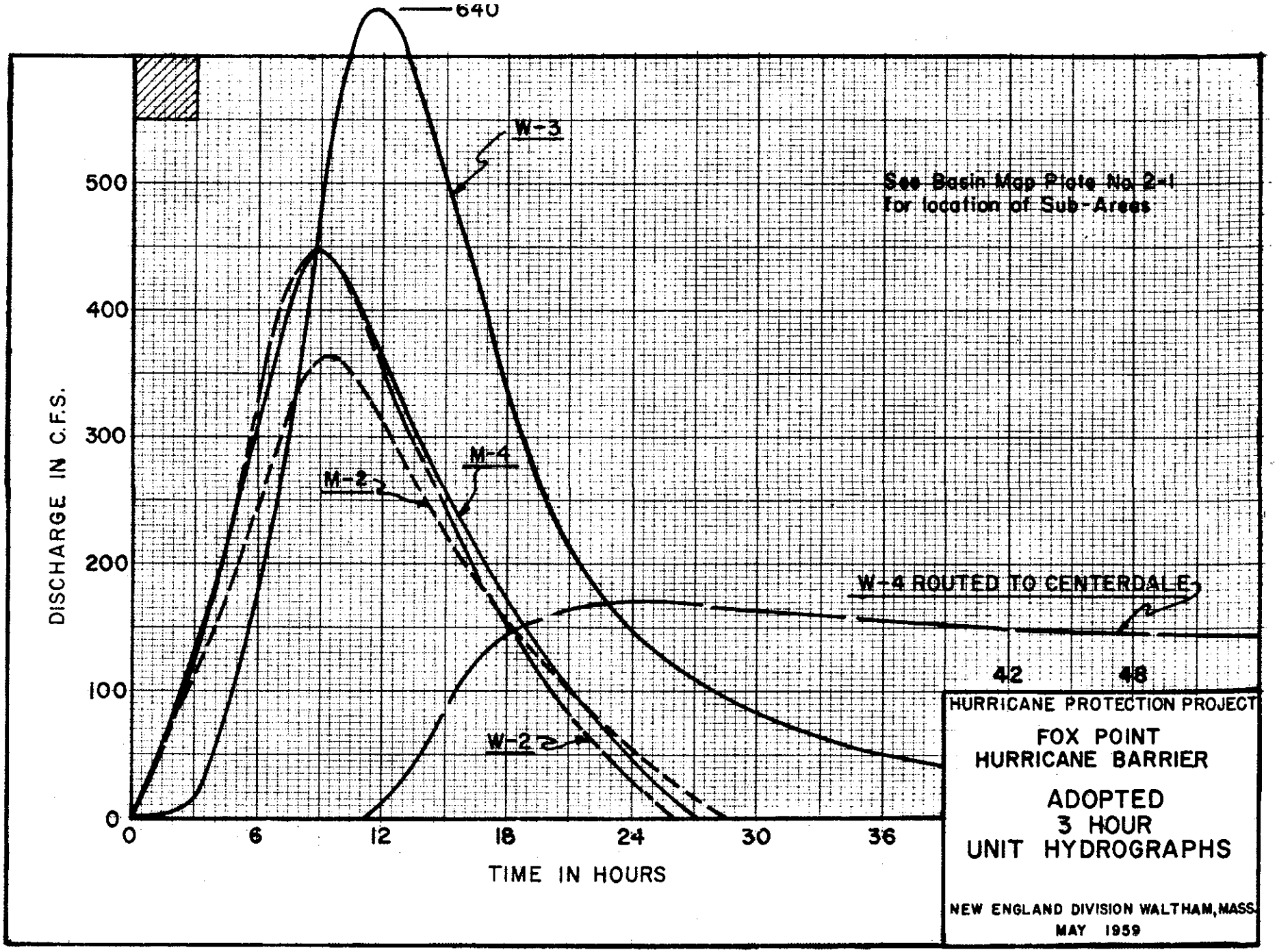
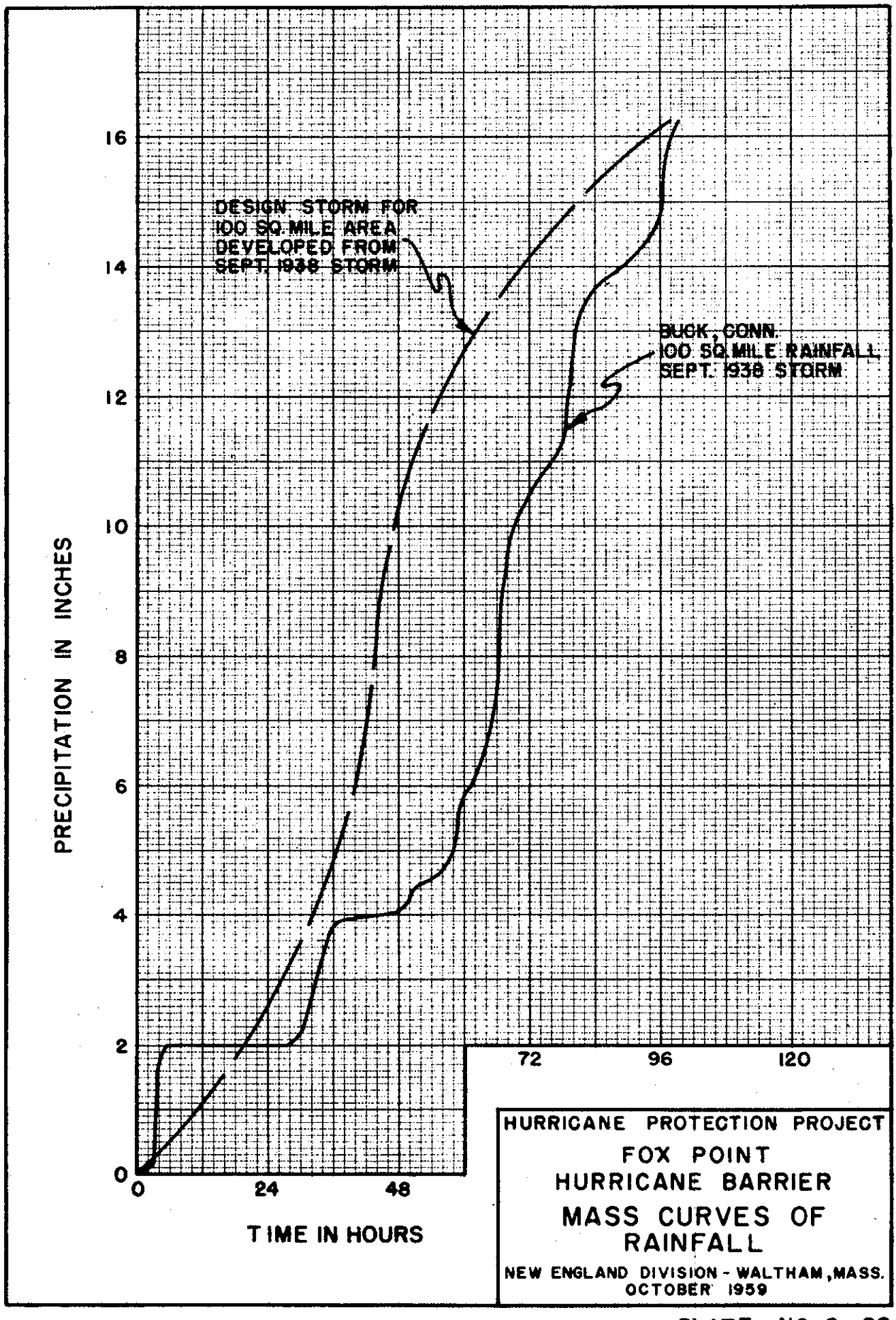

640
W-3
See Basin Map Plate No. 2-1
for location of Sub-Areas
500
400
300
200
100
0
DISCHARGE IN C.F.S.
M-4
M-2
W-4 ROUTED TO CENTERDALE
W-2
0
6
12
18
24
30
36
42
48
TIME IN HOURS
HURRICANE PROTECTION PROJECT
FOX POINT
HURRICANE BARRIER
ADOPTED
3 HOUR
UNIT HYDROGRAPHS
NEW ENGLAND DIVISION WALTHAM, MASS.
MAY 1959

PLATE NO. 2-28



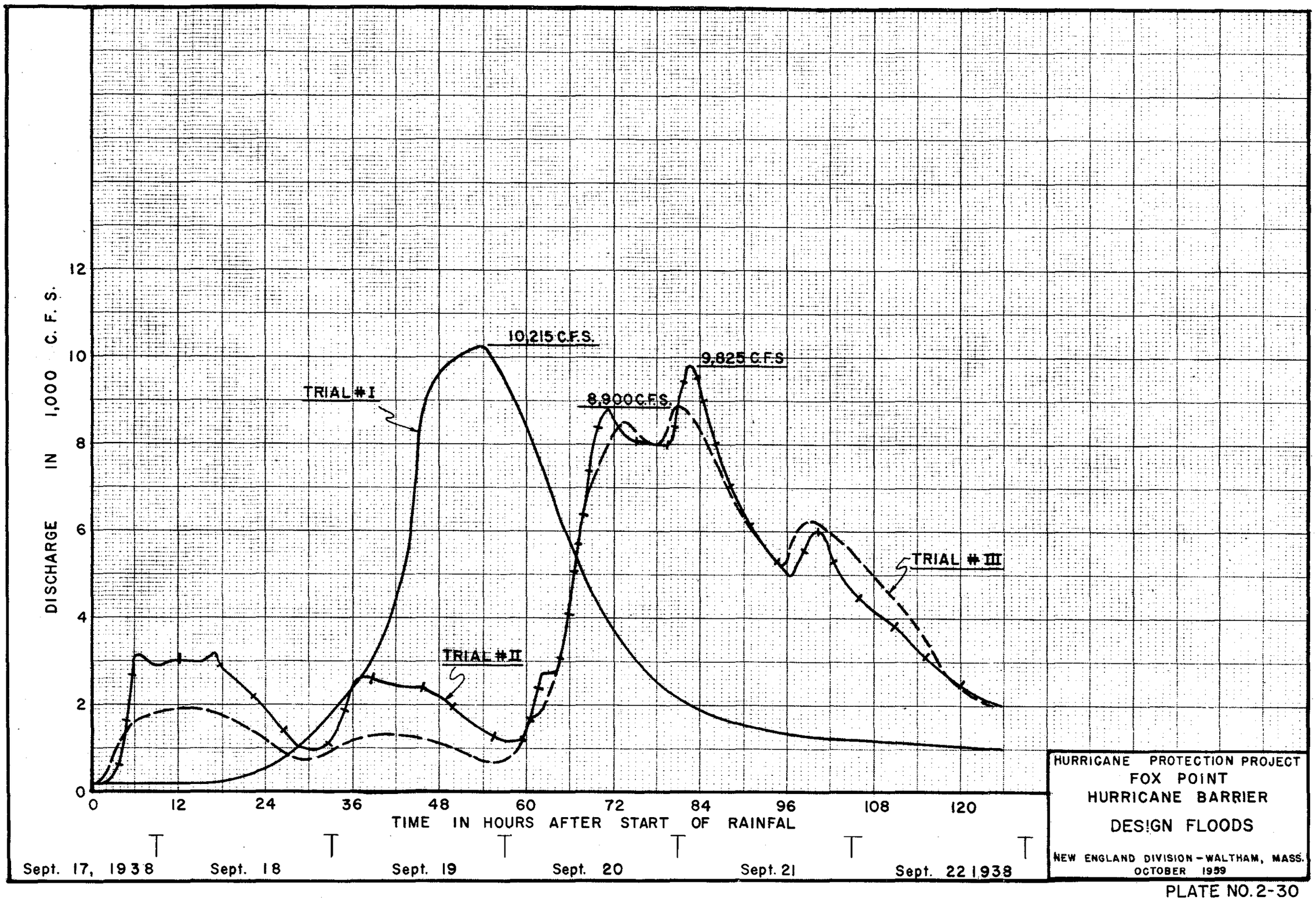
HURRICANE PROTECTION PROJECT

FOX POINT
HURRICANE BARRIER

MASS CURVES OF
RAINFALL

NEW ENGLAND DIVISION - WALTHAM, MASS.
OCTOBER 1959

PLATE NO. 2-29

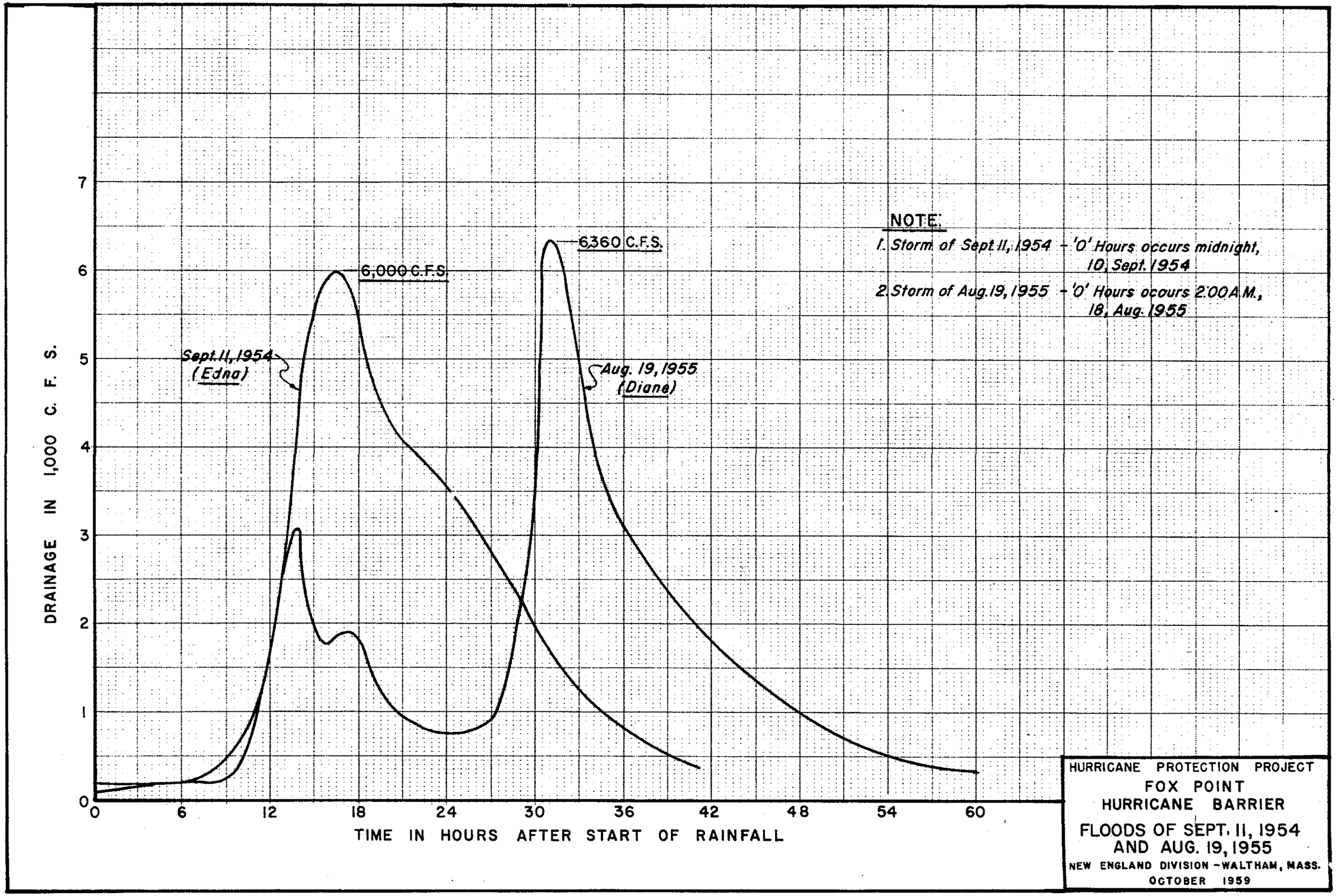


HURRICANE PROTECTION PROJECT
FOX POINT
HURRICANE BARRIER

DESIGN FLOODS

NEW ENGLAND DIVISION - WALTHAM, MASS.
OCTOBER 1959

PLATE NO. 2-30



HURRICANE PROTECTION PROJECT

FOX POINT
HURRICANE BARRIER

FLOODS OF SEPT. 11, 1954
AND AUG. 19, 1955

NEW ENGLAND DIVISION - WALTHAM, MASS.
OCTOBER 1959

PLATE NO. 2-31

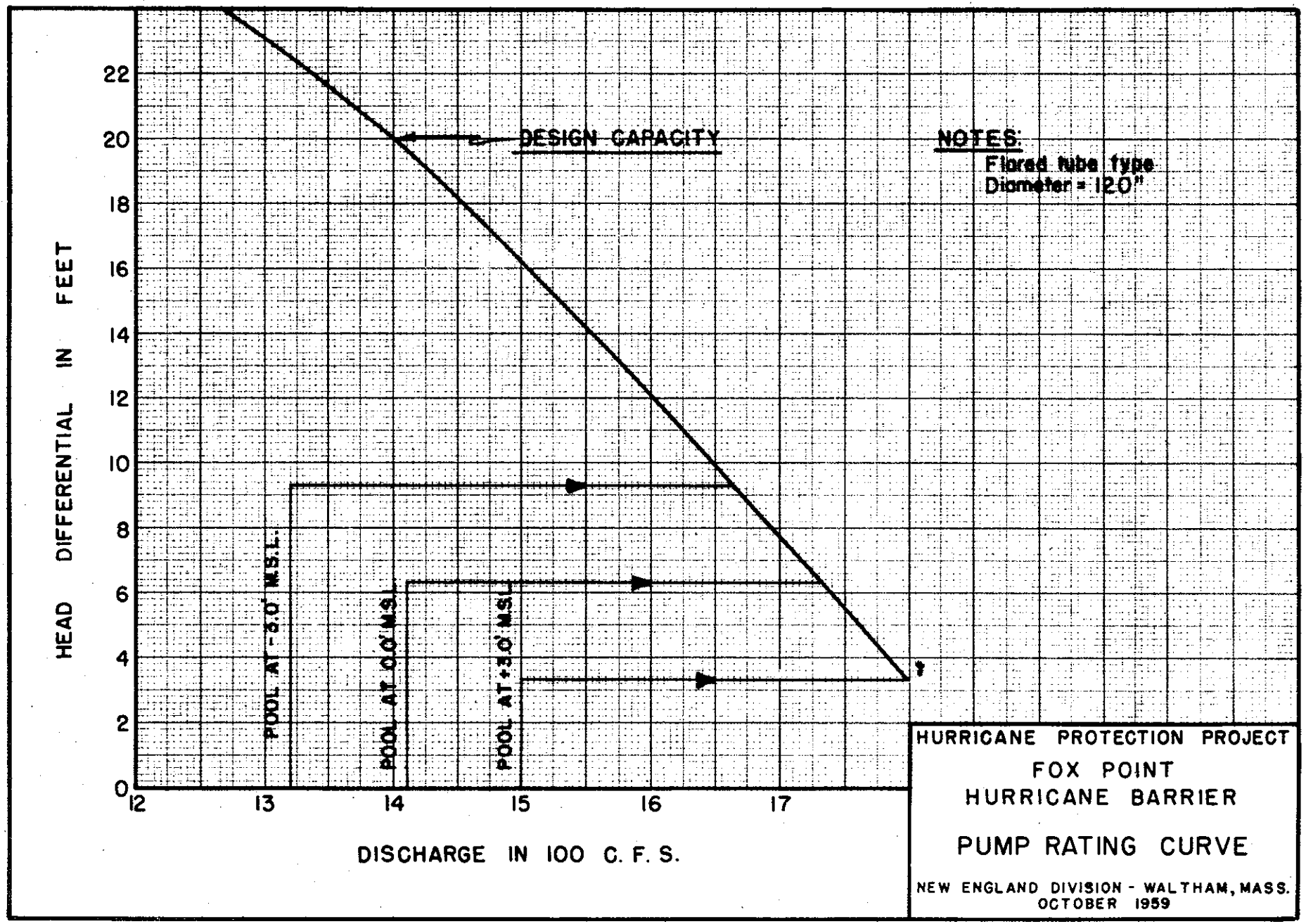

HEAD DIFFERENTIAL IN FEET
0
2
4
6
8
10
12
14
16
18
20
22
12
13
14
15
16
17
DISCHARGE IN 100 C. F. S.
DESIGN CAPACITY
POOL AT -2.0' M.S.L.
POOL AT 0.0' M.S.L.
POOL AT +3.0' M.S.L.
NOTES:
Flared tube type
Diameter = 120"
HURRICANE PROTECTION PROJECT
FOX POINT
HURRICANE BARRIER
PUMP RATING CURVE
NEW ENGLAND DIVISION - WALTHAM, MASS.
OCTOBER 1959

PLATE NO. 2-32

NOTE:

Trial III flood developed from transposed 1938 Storm with weighted losses.

ELEVATION IN FEET – M. S. L.

+16
+12
+ 8
+ 4
0
-4

15.7'

TIDE ELEVATION

585

16,200

POOL ELEVATION

NOTE:

Overtopping Negligible

FLOW IN 1,000 C.F.S.

16
14
12
10
8
6
4

INFLOW

OUTFLOW

Gates Opened

Gates Closed
5 Pumps Operating

Open Gates

Gates Closed
5 Pumps Operating

Open Gates

Gates Closed
5 Pumps Operating

Gates Opened

70 71 72 73 74 75 76 77 78 79 80 81 82 83 84

TIME IN HOURS AFTER START OF RAINFALL

HURRICANE PROTECTION PROJECT
FOX POINT
HURRICANE BARRIER
TRAIL III FLOOD
& 1938 TIDE
NEW ENGLAND DIVISION – WALTHAM, MASS.
OCTOBER 1959

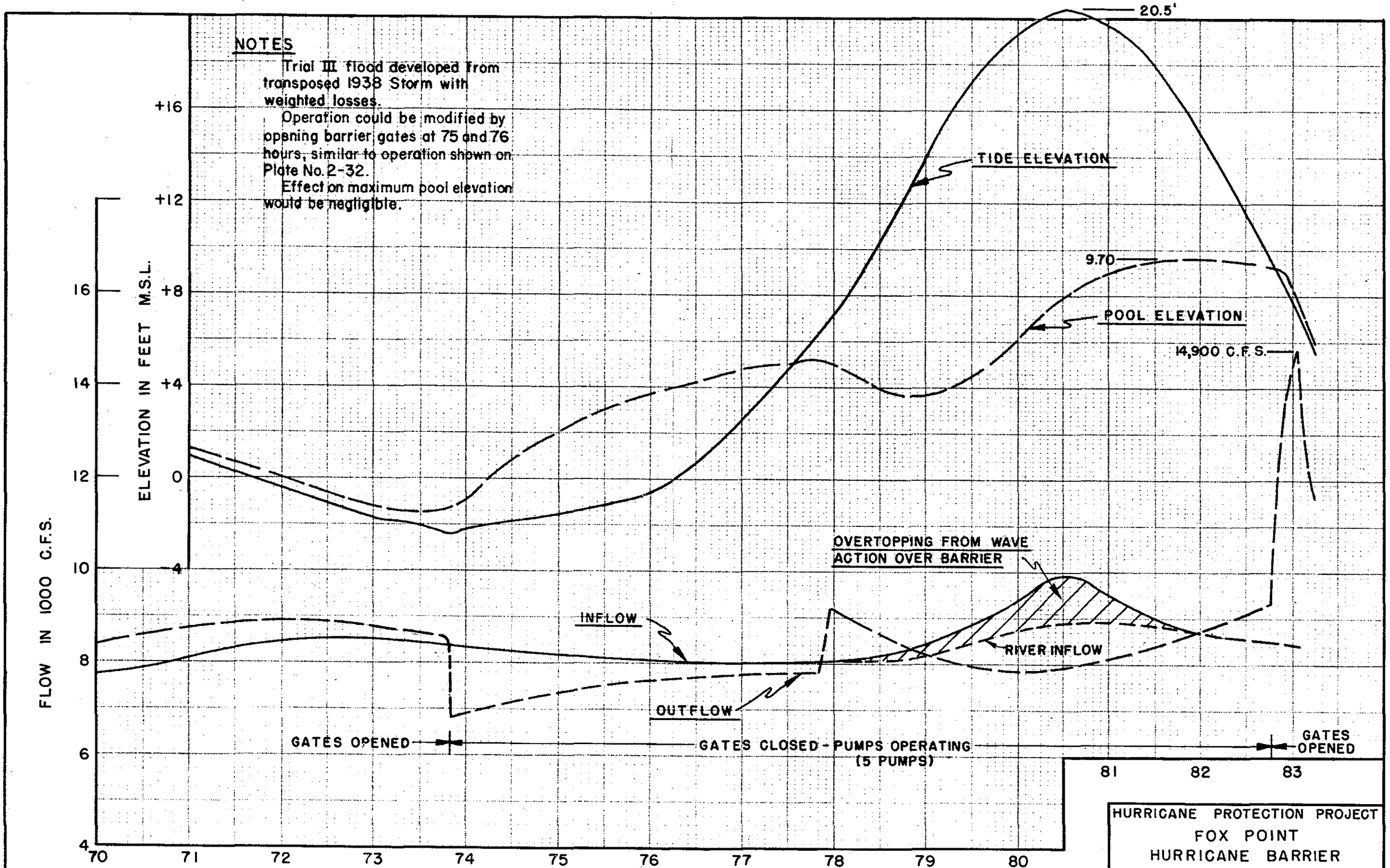
PLATE NO. 2-33

NOTES

Trial III flood developed from transposed 1938 Storm with weighted losses.

Operation could be modified by opening barrier gates at 75 and 76 hours, similar to operation shown on Plate No. 2-32.

Effect on maximum pool elevation would be negligible.



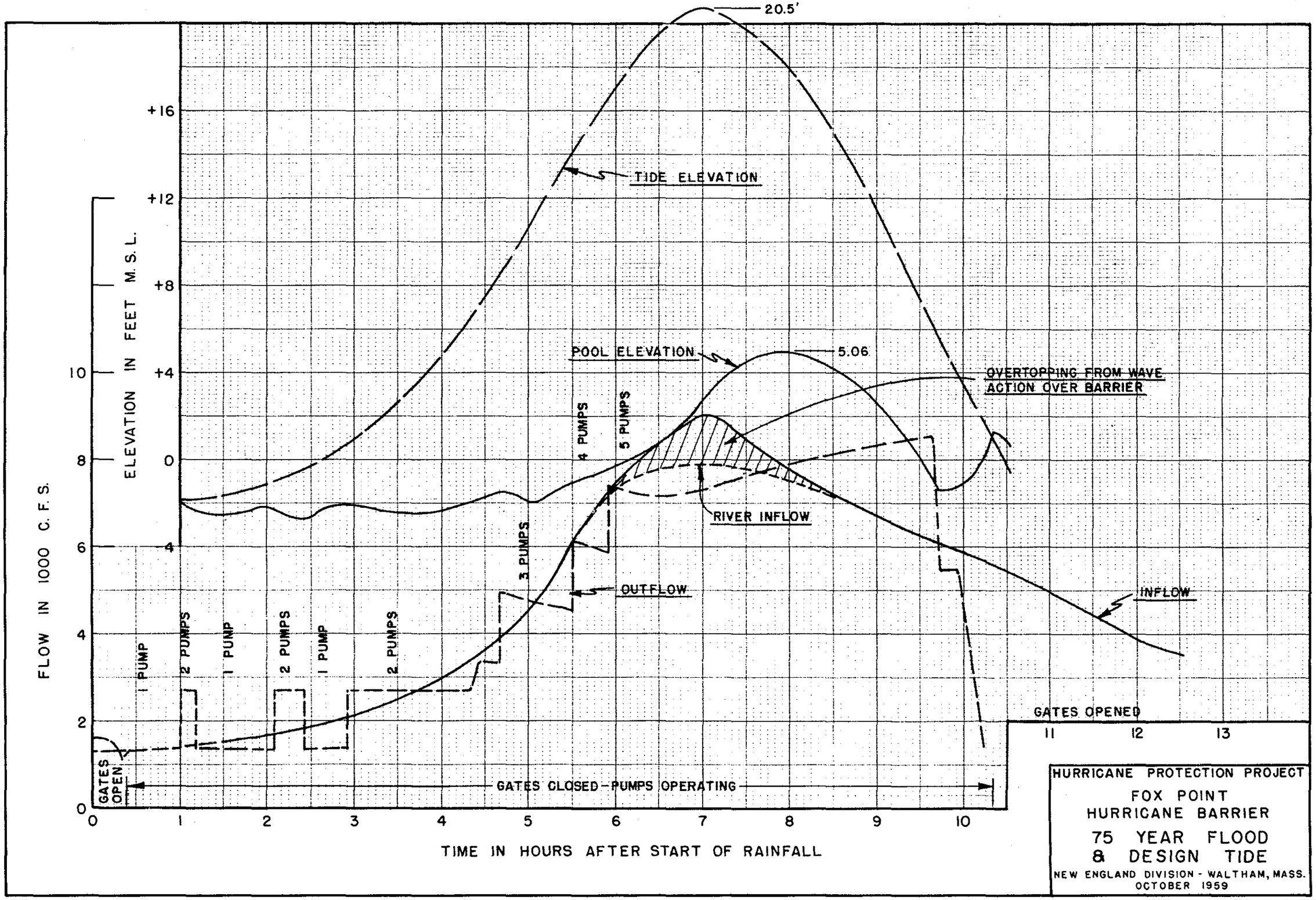
HURRICANE PROTECTION PROJECT

FOX POINT
HURRICANE BARRIER

TRIAL # III FLOOD
& DESIGN TIDE

NEW ENGLAND DIVISION - WALTHAM, MASS.
OCTOBER 1959

PLATE NO. 2-34



HURRICANE PROTECTION PROJECT

FOX POINT
HURRICANE BARRIER

75 YEAR FLOOD
& DESIGN TIDE

NEW ENGLAND DIVISION - WALTHAM, MASS.
OCTOBER 1959

PLATE NO. 2-35